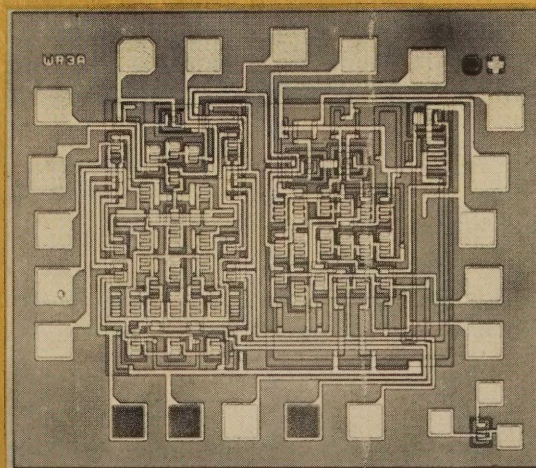
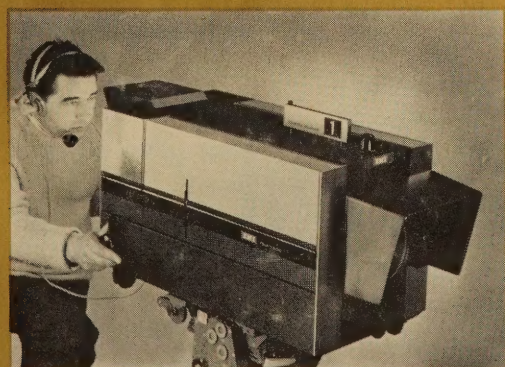
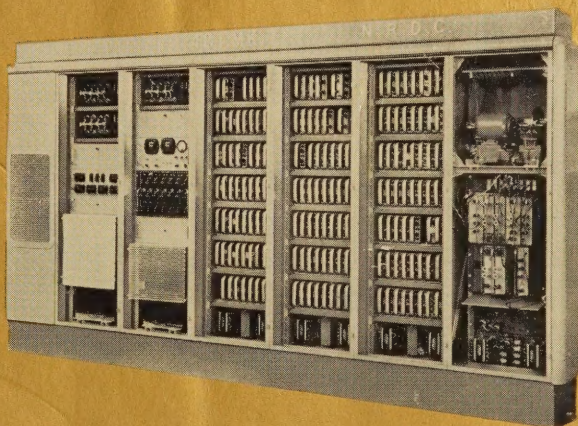
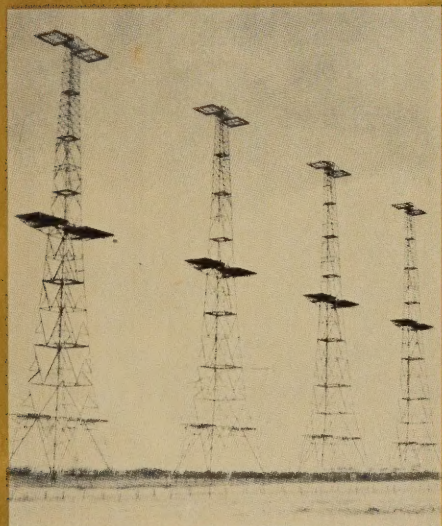
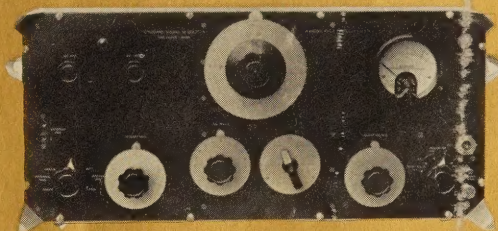
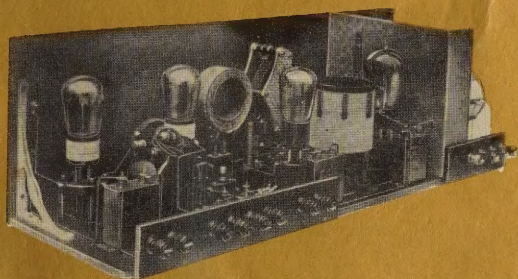


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October 1975

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The Journal of the Institution of Electronic and Radio Engineers

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The cover pictures show some notable milestones in the evolution of radio and electronics:

The 'Everyman Four' receiver. The constructional details for this famous receiver, which set an entirely new standard of m.w. broadcast reception, were published in *Wireless World* in the summer of 1926. It had one neutralized r.f. stage, anode bend detector, RC-coupled i.f. amplifier transformer coupled to an output amplifier, giving about 150 mW to the loudspeaker (*Wireless World* photograph).

The Marconi-Ekco Instruments standard signal generator type T.F. 144. Introduced in the middle 'thirties, this was one of the first production model precision instruments of its kind. This instrument and its variants were the mainstay of radio research and development during the war (Marconi Instruments Ltd. photograph).

The 350-foot transmitting masts for a CH radar station. Erected just in time to play a vital role in the 'Battle of Britain', these stations formed a chain around the east and south-east coasts of the British Isles. They operated on frequencies in the lower end of the short waveband (Crown copyright. Reproduced by permission of the Controller of H.M. Stationery Office).

The Elliott-N.R.D.C. 401 digital computer. Forerunner of one of the earliest series of commercial computers, this machine was publicly demonstrated in London at the Physical Society's Exhibition in January 1953. A brief description of its history was given in the August 1975 issue of *The Radio and Electronic Engineer*, which commemorates the 25th anniversary of the stored program computer, in the paper by Mr. S. L. H. Clarke (Elliott Bros. (London) Ltd. photograph).

The EMI separate luminance colour television camera type 2001. Brought into quantity production in mid-1967 to meet the requirements of colour television in the United Kingdom, this solid state colour camera was one of the first to make use of lead-oxide vidicon tubes (plumbicon). It was described in detail in a paper published in the May 1970 issue of *The Radio and Electronic Engineer* (EMI Electronics Ltd. photograph).

The Plessey WR3A Logarithmic Multiplier Chip. This linear integrated circuit, which is a monolithic bipolar design, is typical of present-day achievement in semiconductor engineering. It is referred to in the paper by Dr. I. M. Mackintosh in this issue (Plessey Co. Ltd. photograph).

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The Contribution of Advertisers

The contents of this Journal show how the Institution's activities have grown from the relatively restricted field of wireless and radio communication to covering the whole field of electronic engineering. This expansion of technology has resulted in the continuous growth of membership and in Journal circulation since 1925.

During the past half century, the enterprise of members in establishing their own Journal has earned the advertising support of manufacturers of radio and electronic equipment and components and ancillary materials; public bodies, educational authorities and publishers have also supported the Journal. This help is appreciated and also provides invaluable information to members and subscribers throughout the world.

In the following pages of advertisements there are illustrations of varied equipment and projects of interest to all electronic engineers. These announcements are therefore a complementary reference to this Golden Jubilee edition of

The Radio and Electronic Engineer

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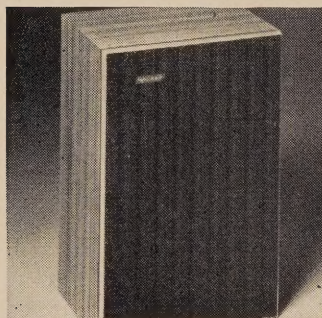
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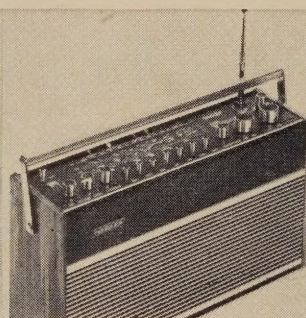
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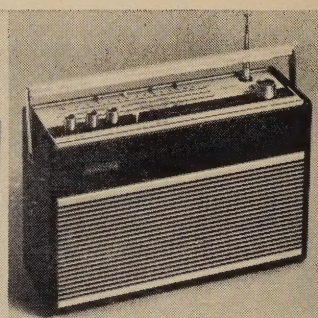
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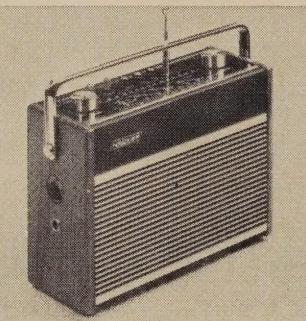
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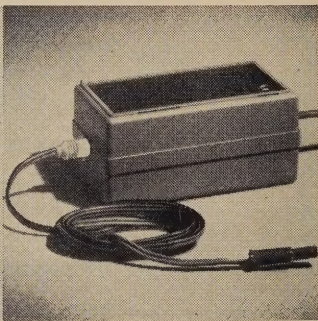
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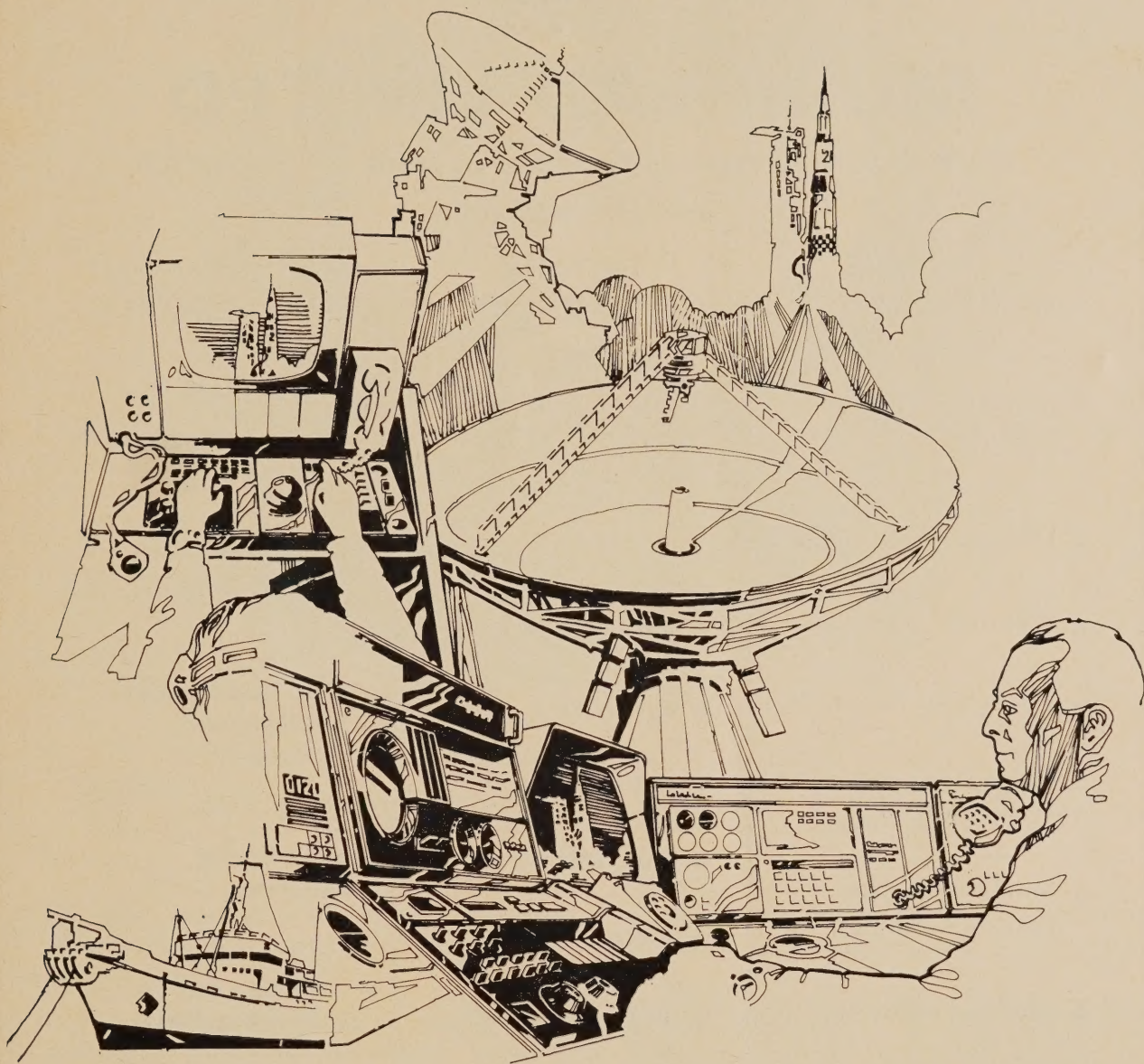
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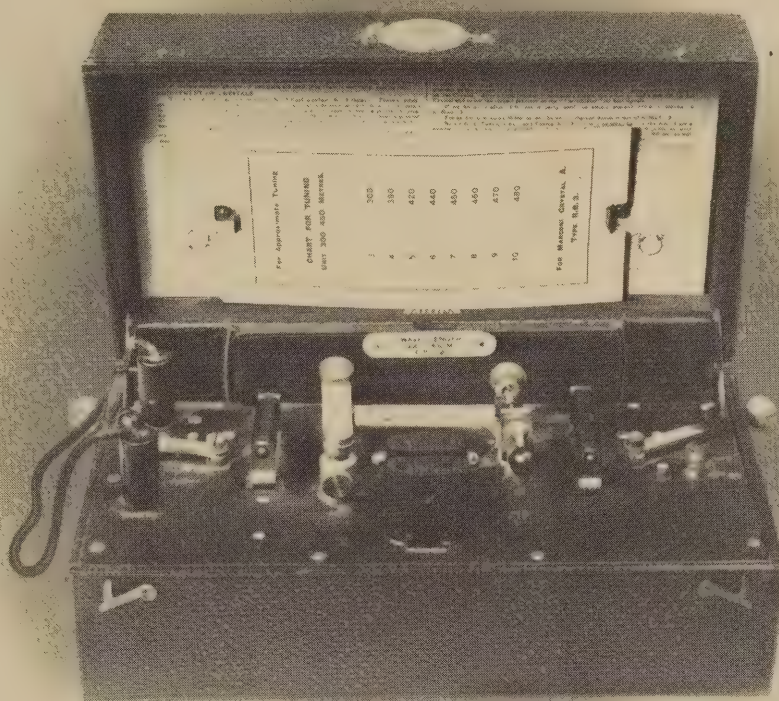
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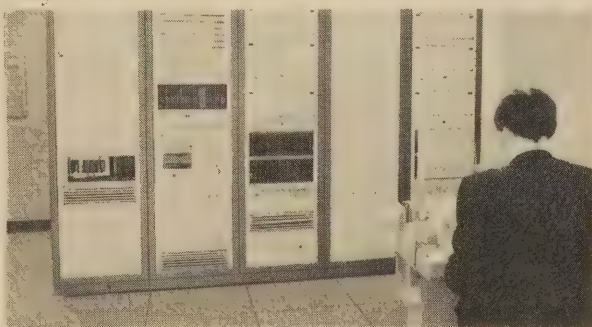
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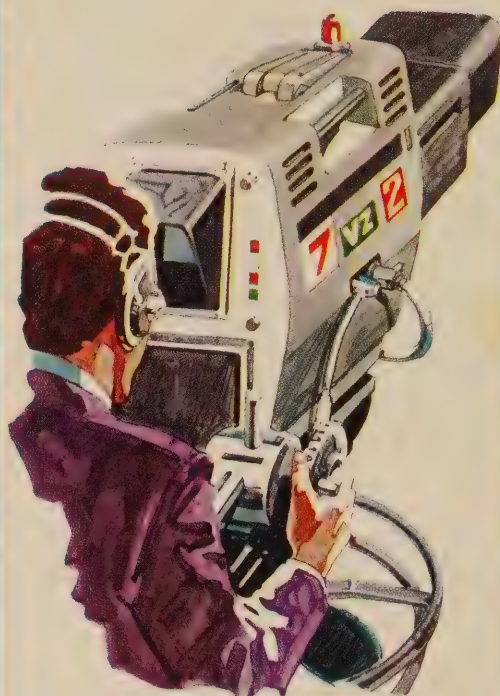
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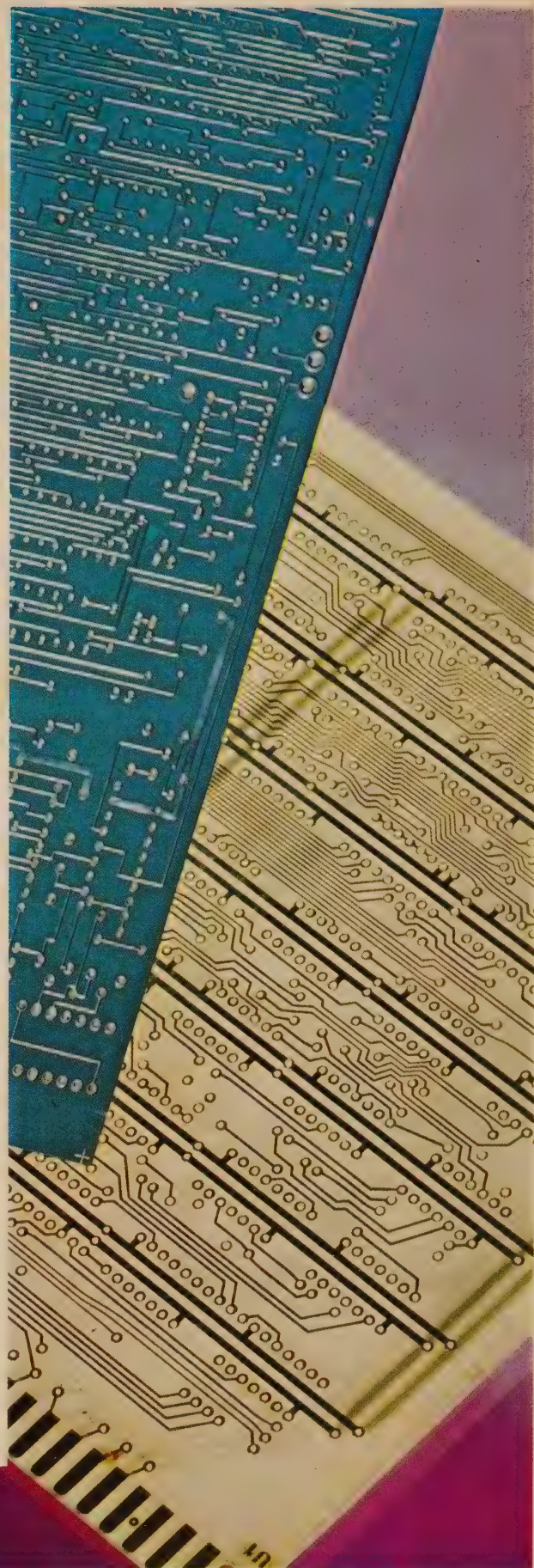
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subjects by the exchange of
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Volume 45 No. 10

October 1975

The Radio and Electronic Engineer

The Journal of the Institution of Electronic and Radio Engineers

A Twentieth Century Institution

AS one of the youngest engineering Institutions it seemed apt that the first history of the IERE should be published under the title 'A Twentieth Century Professional Institution'. This book also gave the background to the science, engineering and manufacture of radio and electronic technology.

Indeed, radio engineering started about the beginning of the twentieth century, when Marconi and many others were almost weekly advancing the new technology. The development of radio and electronics has seen other similar epochs of high excitement, as in the early 'twenties when broadcasting was emerging. It was, of course, at this particular stage that radio engineers were determined to have both a forum and a professional body for their own discipline, distinct from the inhibiting influence of older engineering traditions and teaching.

In the 'thirties, television started its tremendous rise to the power that it is today. The forging of radio weapons for the struggles of the Second World War was another era of high endeavour, one from which many members of this Institution will vividly recall the excitement of ever improving performance, pre-eminently of course in radar, but closely matched in technical achievement by the development of vastly improved communications systems and navigational aids for air and sea.

The decade after the war was the time for the beating of the electronic swords of war into ploughshares for peacetime, and there were two notable developments—the computer and industrial control. The former has been perhaps the more spectacular and brought in its train innumerable ramifications into applications probably undreamt of by its pioneers. Industrial control reminds us of the coining of the word 'automation', about which so much was written in the 'fifties but which withstood the exaggerated claims for its future and steadily and quietly went ahead so that many would hardly realize the extent to which industry today has become 'automated'.

During the 'fifties and 'sixties the incentive of new horizons was once again high in television and saw the growing technical complexity of the domestic receiver. Despite two decades of inflation, television and radio receivers still carry substantially the same price ticket and represent a technological bargain to the consumer that few industries can match (except perhaps that of the hand-held calculator!). The television saga then went on to the great days of the colour systems controversy and has also sparked off many ancillary developments.

Similar stories of how new electronic techniques have improved communications, navigational aids, radar, etc., can be related. But probably our earlier reference to the incentives of innovation apply most strikingly to the impact of electronics on the 'new' technologies—medical electronics, ocean technology, nuclear power and, of course, space exploration. None of these could have progressed very far without the ingenuity of the electronic engineer. Superimposed over all these applications of electronics have however been some of the most exciting developments of all, which indeed have made them possible: the semiconductor revolution that started in 1948 and still finds startling new developments that surprise even the experts; the optoelectronics revolution, involving lasers and optical fibre communication, techniques still in relative infancy; and the component technology revolution bringing new devices that are ever smaller and more reliable than their predecessors and contribute to the versatility of electronics in so many ways.

The contents of this Golden Jubilee Issue of the Institution's Journal were invited so as to highlight the developments which have taken place during the lifetime of the IERE. In this Commemorative Issue we have assembled essays by senior members of the Institution who, in nearly every case, 'were there' at the vital time. We hope that the collection of essays will be found individually enlightening to those who are not too familiar with particular areas of endeavour and, at the least, nostalgic to the specialist. Already 'A Twentieth Century Professional Institution' needs bringing up to date; the Institution has successfully met change and challenge. Who would forecast development in the next 50 years?

G. D. CLIFFORD

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K.G., P.C., G.M.S.I., G.M.I.E., G.C.V.O.,		Major-General Sir Leonard Atkinson, K.B.E.,	
K.C.B., D.S.O., D.C.L., LL.D.	1947-48	B.Sc.	1967-69
Leslie Herbert Bedford, C.B.E., M.A., B.Sc. (Eng.)	1949-50	H. F. Schwarz, C.B.E., B.Sc.	1969-71
Paul Adorian	1951-52	A. A. Dyson, O.B.E.	1971-73
William Edward Miller, M.A.	1953-54	Sir Ieuan Maddock, C.B., O.B.E., D.Sc., F.R.S.	1973-75
Rear-Admiral Sir Philip Clarke, K.B.E., C.B., D.S.O.	1955-56	H.R.H. The Duke of Kent, G.C.M.G., G.C.V.O.,	1975-

(The office of President did not exist during the first seven years of the Institution's existence—Mr. James Nelson was Chairman from 1925 to 1931.)

Membership Roll for the First Decade

The Institution's records show that the following members joined the Institution during its first decade, and have therefore 40 years or more of membership to their credit:

E. S. Ahl, <i>Associate 1934, Member 1947</i>	D. G. Mackenzie, <i>Associate 1928</i>
L. T. Barnes, <i>Student 1933, Member 1940</i>	Squadron Leader J. F. Mazdon, M.B.E., RAF(Ret.), <i>Associate 1931, Fellow 1945</i>
H. J. Barton-Chapple, <i>Honorary Fellow 1933</i>	W. E. Miller, M.A., <i>Fellow 1932, Honorary Fellow 1966</i>
W. J. Blackwell, <i>Associate 1935, Fellow 1943</i>	Admiral of the Fleet The Earl Mountbatten of Burma,
A. C. Brittain, <i>Associate 1934, Member 1937</i>	K.G., P.C., <i>Fellow 1935, Honorary Fellow 1965</i>
S. Brown, <i>Member 1931</i>	J. W. Murray, M.B.E., <i>Associate 1931, Member 1955</i>
G. F. Budden, <i>Associate 1935, Member 1957</i>	Lieutenant-Colonel C. F. Newton-Wade, R.Sigs(Ret.),
S. R. Burbidge, <i>Associate 1933, Member 1938, Fellow 1961</i>	<i>Fellow 1926</i>
B. J. BurrIDGE, <i>Member 1935, Fellow 1950</i>	W. G. J. Nixon, <i>Associate 1933, Member 1943, Fellow 1946</i>
R. J. Canaway, <i>Student 1934, Associate 1938</i>	L. H. Paddle, <i>Fellow 1927</i>
T. H. Colebourne, <i>Associate 1933, Member 1938</i>	C. C. Phillips, <i>Fellow 1926</i>
Major W. E. Corbett, R.Sigs(Ret.), <i>Associate 1934, Member 1936</i>	G. M. Preedy, <i>Member 1934</i>
T. G. Cottam, <i>Member 1932</i>	H. L. Ranson, <i>Associate 1931, Member 1933</i>
T. A. Cross, <i>Associate 1935, Fellow 1942</i>	A. K. Sanderson, <i>Student 1927, Member 1945</i>
W. A. Davis, <i>Associate 1935, Member 1939</i>	A. J. Selby, <i>Member 1926</i>
A. S. Dunstan, <i>Member 1934</i>	A. M. Sellick, <i>Member 1926</i>
Major A. W. Grantham, R.Sigs(Ret.), <i>Associate 1933, Member 1938, Fellow 1943</i>	G. P. Sentance, <i>Associate 1931</i>
D. A. Griffith, <i>Associate 1935, Member 1937</i>	J. H. Setterfield, <i>Member 1935, Fellow 1943</i>
J. F. Harris, <i>Associate 1933, Member 1938</i>	W. B. Smith, <i>Associate 1935, Member 1938</i>
H. G. Henderson, <i>Associate 1929, Member 1932, Fellow 1942</i>	J. S. Stewart, <i>Associate 1934</i>
W. F. G. Jones, <i>Member 1934</i>	E. A. W. Spreadbury, <i>Associate 1934, Member 1937, Fellow 1947</i>
O. B. Kellett, <i>Member 1931, Fellow 1938</i>	J. Tilley, <i>Fellow 1931</i>
N. C. Kermode, <i>Member 1932</i>	H. J. E. Veal, <i>Associate 1934, Member 1944</i>
G. F. N. Knewstubb, <i>Associate 1933, Member 1942</i>	O. V. Wadden, <i>Associate 1933, Member 1938</i>
R. A. Lovibond, <i>Member 1933</i>	A. J. Warner, <i>Associate 1934, Member 1936</i>
C. Lunt, <i>Associate 1934, Member 1937</i>	F. K. Webb, <i>Student 1935, Associate 1936, Member 1938</i>
	S. R. Wilkins, <i>Associate 1934, Member 1938, Fellow 1942</i>

Note.—Classes of membership shown use the present nomenclature as adopted in 1968.



Semiconductor Devices—Portrait of a technological explosion

IAN M. MACKINTOSH, Ph.D., F.Inst.P., C.Eng., F.I.E.E., F.I.E.R.E.

The explosion started with germanium devices, which were quickly eclipsed by silicon. The subsequent developments were the bipolar integrated circuit and the emergence of metal-oxide semiconductor techniques which could well be supplanted in some applications by charge-coupled devices.

Not so much a paper, more a personal view. It seemed easy, the way the Editor put it, to contribute an 'essay' on Semiconductor Devices, and I readily agreed. But when the time came to make the preliminary outline, the first sketch, I found that the canvas all too rapidly filled up with a kaleidoscope of images, personalities and events. How on earth to discipline the pen to give some flavour of how things were in the early days, where we have come to and what may lie ahead—without blinding the acolyte with science or boring the savant—or, indeed, writing an entire book.

How (compounding the problem) to avoid dwelling on the tempestuous contributions of the late Jack Morton, Vice-President of Bell Telephone Laboratories (worthy by himself of an entire book); how to handle the impact of personalities as fascinating and diverse as Shockley, Bardeen and Brattain, or Noyce, Haggerty and Hogan, or Welker, Gunn and Esaki; how to pay due attention to solid-state lasers, microwave devices, thyristors, light-emitting diodes and a host of other devices while at the same time giving necessary pride of place to the transistor and—of the greatest economic consequence of them all—the integrated circuit?

The answer, of course, is quite simple: it can't be done. At least, not in the space available to me in this Golden Jubilee Issue. What follows, therefore, is an entirely personal view of events, aspects of the industry, water-sheds of technical development, economic factors etc. which seem important to me, and let me apologize at

the outset if there is a less than perfect correlation between what you think and I think is important or interesting.

The First Decade: 'Ma' Bell Gives Birth

Although there had been various types of semiconductor devices such as the cat's whisker and the selenium rectifier around before 1948, the work carried out by Bardeen and Brattain¹ and Shockley² on the behaviour of semiconductor surfaces, minority carriers and the solid-state amplifier had mainly involved germanium. This state of affairs continued and in the 1950s it was all germanium, although Welker³ in 1952 had elegantly proposed that III-V compounds might also be interesting. (Indeed, his paper was so convincing that my own first post-graduate years were spent researching the properties of indium antimonide—which seemed to promise so much but has provided so little.) In Europe and the United States, practically every manufacturer with any electronic pretensions—and especially the thermionic valve producers—were getting into the act, and Philips—by combining its excellent capabilities in both research and production engineering—was emerging as a world leader in the alloy germanium transistor business.

In 1956 I emigrated to where the action was (i.e. Bell Telephone Laboratories, or 'Ma' Bell to its intimates) and I vividly remember, in the late autumn of that year, the standing ovation given in the Murray Hill Arnold Auditorium to Walter Brattain at the end of the announcement of his award (together with Bardeen and Shockley) of the Nobel Prize for Physics in recognition of their invention of the transistor.

What a fantastic place Bell Laboratories was in those days (is it still, I wonder?). With great percipience, BTL had decided that for various reasons germanium was probably not good enough in the long run, so that practically everybody there seemed to be working on silicon. Major breakthroughs came at what—with hindsight—was an astonishing speed. Given the existing capability to produce good quality crystal ingots from very high purity silicon, the first breakthrough, in sequence and importance, was diffusion. The majority of semiconductor laboratories throughout the world were heavily committed to developing ever greater refinements to the tricky alloying process which was at

Dr. Ian M. Mackintosh (Fellow 1964) is Chairman and Managing Director of Mackintosh Consultants Company Ltd., an international firm of consultants which he formed in 1968 to specialize in providing services to the electronics and allied industries. His involvement with the semiconductor industry goes back over 20 years to his original research work on III-V compounds. This was followed in 1956 by six years with Bell Telephone Laboratories. Later, he was at Pittsburgh for about two years as a Department Manager in the Westinghouse Central Research Laboratories. After returning from the United States in 1964, Dr. Mackintosh became General Manager of Elliott-Automation Microelectronics Ltd. Dr. Mackintosh was the industrial adviser to the UK delegation to the OECD Study of the Technology Gap, and he also served for five years in a part-time capacity as a Visiting Industrial Professor of the University of Edinburgh, and is a Council Member of the Council for National Academic Awards.

the heart of the production of germanium transistors. At Bell, however, it has been recognized that the solid-state diffusion process offered in principle much higher prospects of the greater control and precision of p-n junction formation which would be required if transistors were ever to perform at the high frequencies of relevance to the Bell System—and, indeed, to most other applications. As it happened, diffusion into germanium proved to be relatively difficult but success came more easily with silicon, and it was a development to which a substantial number of workers contributed.⁴

Today, billions of silicon transistors later, it is easy to recognize this as a vast leap-frogging of technology into wholly new realms of technical possibility. Yet even in those days a surprisingly large number of organizations (very few of them, regrettably, outside the United States) realized the importance of the development, and the twin band-wagons of silicon and diffusion began slowly to roll.

Next came oxide masking. It was all very well being able to diffuse a junction, more or less uniformly, into a thin slice of high-purity, single-crystal silicon, perhaps 2 cm in diameter. If one began, say, with a p-type slice and diffused in a layer of phosphorus, for example, from both sides one ended up with a nice n-p-n sandwich, but there were difficulties in contacting the inner (base) layer. Even with the relatively crude dimensions of those days,† it was not easy to etch away a portion of one of the n-layers to make contact to the p-type base layer. How much easier, some thought, if we could somehow or other permit the impurities to diffuse in only in certain areas, so that the original p-type crystal surface would still be available for making contact to the base region. And, indeed, that is just how it turned out in a classical piece of research by Frosch and Derick.⁵

In the process which finally evolved, as is now well known, the ultra-clean polished surface of the silicon slice is first oxidized to a uniform thickness of SiO₂, and this is then etched away in selected areas by a sophisticated form of photolithography.‡ During the diffusion process, therefore, the impurities are barred from entering the silicon except in the areas where the oxide has been removed, and a relatively intricate transistor structure can be obtained.

Unfortunately, the structures didn't work too well in those days, and much device analysis work was simultaneously going on to try to improve our understanding of the carrier transport mechanisms. It seems to me worthy of comment that things which we then found so difficult to understand now seem so incredibly simple. As one example, the emitter concentration effect,

† To give some idea of the scale of things, those of us involved with diffusion processes thought in those days in terms of controlling junction depths, at best, to a few microns; today, control to tenths of a micron is commonplace.

‡ I can still vividly remember working in 1957 with H. H. Loar using a simple plate camera and an illuminated white card on which we had stuck some strips of black tape, in one of the first attempts (in the semiconductor industry) to produce a crude photo-etching mask.

whereby a junction tends to emit carriers less strongly at its centre due to the potential drop created by the base current flowing 'laterally' along the narrow base region. I believe that the reason why this very simple effect was not instantaneously obvious to us all was that only a few individuals in those days were relatively clear in their minds about what was going on inside these structures. There were, of course, many conflicting views of mechanisms which might be happening and it inevitably took time, and much debate and experimentation, for the truth gradually to emerge. In my view, the great strength of the Bell Laboratories in those days was that literally dozens of first-class individuals were working on the problems so that, in particular, the rate of cross-fertilization of ideas was speeded up immensely.

I would like to quote another simple example, not only because I was involved in it myself but also because from it sprang a far deeper understanding of an extremely important new structure, the p-n-p-n device. Shockley⁶ had already described the theory of the 'hook-collector transistor', some excellent work by Moll *et al.*⁷ had resulted in the development of the p-n-p-n diode and I had myself established the basic theory of, and fabricated the first p-n-p-n triode⁸—later to be developed by Gentry⁹ into the silicon controlled rectifier (s.c.r.). But these 'four-layer' devices suffered from the major disadvantage that, when subjected to a train of voltage pulses (i.e. with a specified leading edge 'ramp'—or dV/dt), the 'breakover voltage' decreased as the accumulated number of pulses increased. For those laboratories working on p-n-p-n diodes, this was an extremely embarrassing effect which, although not at all understood, was vaguely believed to be due to some internal-junction heating process and was labelled the 'hot and cold' effect.

More or less by accident, however, I observed a little later that this objectionable effect gradually disappeared as the etching time of the p-n-p-n diodes was increased (our almost complete ignorance of the surface properties of silicon led us to do some very strange things in those days), from which I was able to show that the etching process had actually produced a pimple (or 'mesa') structure underneath the gold lead which was in position during the etching (therefore acting as a mask against the etchant). From this it was a short step indeed to the realization that we were in fact dealing with a capacitive, not a thermal effect.¹⁰

Today it really does seem incredible (doesn't it?) that we understood so little about the interactive effects of three p-n junctions charging and discharging in series that we couldn't see a capacitive phenomenon even when it was staring us in the face. Or perhaps we were all simply stupid, but in light of the many talents involved in working on the problem, I really don't think so. Perhaps today's researcher, similarly bemused by an apparently inexplicable effect, can take comfort from the fact that it sometimes happens in the best of circles.

Although the group at Murray Hill of which I was a member was preoccupied with silicon devices, things were by no means quiescent on the germanium front. Outside Bell Labs, Philco and Philips were particularly successful in achieving further technological refinements,

and things looked very bright for the former's micro-alloy-diffused transistor (m.a.d.t.), announced in 1958.¹¹ Here was a device, with the inherent advantage of germanium's high carrier mobilities, which was based on a sophisticated combination of diffusion and alloying and which could be manufactured in massive quantities by a semi-mechanized process. With an apparently unbeatable high-frequency performance, and with—by the standards of those days—very low predicted manufacturing costs, the m.a.d.t. made things look bad indeed for silicon, and companies throughout the world (prominent among them Plessey) began to obtain Philco licences and to make major financial commitments to m.a.d.t. production facilities.

But all was not yet lost for silicon. Although I am oversimplifying a little, it was becoming widely recognized that the primary frequency-limitation factor in silicon transistors was the collector RC time-constant, and not base width or carrier mobilities. Since the main culprit was collector resistance, one possibility was to reduce significantly the slice thickness (i.e. to shorten the resistor 'length' between the collector junction and the 'back' contact), but this led to severe handling difficulties and to considerable yield losses due to breakage of the thin slices. Another possibility, in principle, was to increase the conductivity of the collector but this implied higher junction capacitances as well as several other difficulties.

At Bell Labs, in recognition of these facts, work had quietly been restarted on a relatively old technology for growing a layer of crystalline material on a substrate (in this case, of the same material). As applied to silicon, of course, this would in principle permit the growth of a thin, high-resistivity layer on a thick, high-conductivity substrate with the promise, therefore, of high-frequency transistors which could be made at high manufacturing yields. The result, as the world of electronics now knows, was the epitaxial process¹² which, although more or less simultaneously being applied by Siemens and Motorola to germanium, had an electrifying effect on the prospects for silicon and effectively sounded the death-knell for the m.a.d.t. Because here was the last piece of the technological jigsaw required to make high performance, high-reliability silicon transistors:

A relatively high band-gap element (capable, therefore, of providing higher temperature device operation than germanium) which could be produced in an extremely pure, crystalline form relatively cheaply.

Good-quality, high-conductivity 'substrate' slices, relatively free from imperfections.

An epitaxial process capable of growing on these substrates thin, high-resistivity silicon layers of device quality.

An oxide-masking, photolithographic technique of high enough precision to permit the small structures required for high-frequency performance.

Well-controlled and precise diffusion processes (for both n- and p-type impurities) to give shallow emitters and narrow base widths.

And as a final bonus, it was later discovered that the

layer of oxide inherent in this processing method not only provided some protection from handling faults which could arise during processing, but also gave the completed device considerable immunity from its working environment (e.g. from the presence of small amounts of moisture or other contaminants) and hence led to considerably higher device reliabilities.

All of this, of course, is inevitably an over-simplification of things to a degree but it does represent, in my view, the basic essentials of what had become, by 1960, an overwhelming case against the future of germanium. And the astonishing thing to my mind is that despite significant contributions from many other individuals in several laboratories,[†] the major developments in all of these areas of silicon technology stemmed primarily from Bell Laboratories during roughly the second half of the decade (the 1950s) which effectively began with their invention of the transistor. This record is comparable, I believe, with the nuclear physics research of the Cavendish Laboratory earlier in the century in the quality of the sustained and comprehensive contribution to scientific progress made by a single laboratory. It would be of interest to analyse more of the basic reasons for this great decade of Bell's creativity, but that is obviously outside the scope of this paper.

Intermission: Time Out from Silicon

At this stage the transistor industry was about to embark on an even more astonishing decade of technological advance and industrial growth, but before I launch into that I would like briefly to outline some of the major developments which were taking place outside the mainstream of the germanium: silicon battle.

First in chronological sequence came the tunnel diode, first described by Esaki in 1958.¹³ Again with hindsight, what a beautifully simple idea—to form a p-n junction between two such highly-doped regions that, in equilibrium, the continuity of the Fermi level across the junction would result in an energy barrier to the flow of carriers in the 'forward' direction. The device thus presents a high impedance at low forward bias, progresses through a region of negative impedance and then into a fairly normal 'forward' region of positive resistance.

What immense possibilities this tunnelling device seemed to offer. Apparently simple to manufacture, with potential applications as both a switch and an amplifier, only two terminals to bother about, and a very high speed of operation due to the basic tunnelling mechanism employed. Talk about bandwagons! Within months practically every electronics conference in America (and presumably in Japan and Europe also)—whether on materials, devices or applications—was dominated by the tunnel diode. Armies of talent were employed in an attempt to capitalize on this marvellous new device, but the dawn of reality came relatively swiftly. It is difficult to itemize all of the reasons for the failure of this concept but foremost among them, in my view, were production

[†] A list of references would be either invidious or too lengthy to be of value.

control problems (i.e. the difficulty of producing at high yields tunnel diodes of specified negative resistance characteristics) and the very substantial problems of designing complex systems around a two-terminal device (i.e. the third 'control' electrode was sorely missed).

In any event, the tunnel diode—despite its undoubted scientific interest—has, so far at least, made an insignificant commercial impact, and none of the many other forms of tunnelling devices which it spawned has yet successfully completed the transition from research laboratory to volume production. In my view, it is unlikely that any will,† due primarily to the production control problems referred to above.

At about the same time we began to see the first serious applications of semiconductor devices in the microwave field and here the story has been very different. Instead of the tunnel diode's meteoric rise and catastrophic fall, the microwave story is one of diligence, patience and accelerating success to the point where the range of semiconductor microwave devices—mainly silicon or gallium arsenide—is now very extensive.¹⁴

And finally in this brief diversion from the story of the transistor there is the great field of opto-electronics, described in a companion paper,¹⁵ in which semiconductor devices have again had a major role to play. Over the years much work has been carried out on the band structure of a wide range of semiconductor materials and on their basic properties, including a substantial volume of work on trapping mechanisms and radiative recombination processes.¹⁶ From this work it became clear that, under certain circumstances, it should be possible to obtain light output from some materials and the first successful device based on these principles was reported by Starkiewicz and Allen in 1962.¹⁷ At more or less the same time, work was going on to improve the maser¹⁸ and these concepts were soon translated into the optical laser.¹⁹ Very rapidly it became clear that a wholly solid-state laser was a relatively simple proposition and a number of workers^{20–22} reported at about the same time the creation of such a device using gallium arsenide. So far it has remained largely of scientific rather than commercial importance mainly because the number of applications for such low-power sources of coherent light is quite limited. (However, an important application is now looming in fibre optic communications.)

Not so, however, for the non-coherent solid-state light sources which emerged as the control of the properties of III–IV compounds such as GaAs, GaP and mixtures thereof was gradually improved, and as practical p–n junction technologies were developed for these materials. To cut the story short, the last ten years or so have seen the development of the light-emitting diode into an electronic component of major industrial significance, as best indicated by its widespread use in the ubiquitous electronic calculator. In my view this is really only the beginning of the story.

† The only exception, although not directly comparable to the tunnel diode, will probably be a range of m.n.o.s. (metal nitride oxide semiconductor) silicon programmable memories which rely for their operation on quantum mechanical tunnelling.

The 'Sixties: Planar and Simpler

Meanwhile, a small company, primarily involved in the field of geophysics, had spotted what was going on and, around the mid-1950s hired Gordon Teal who was at that time one of the foremost authorities on growing semiconductor crystals.²³ From this beginning Texas Instruments rapidly grew to become the world's leading supplier of silicon devices and, in fact, has remained Number One ever since, successfully assimilating several climactic changes in technology, markets and production economics.‡

And, as the 1950s came to an end, another smallish company, Fairchild Camera and Instruments, was in the process of announcing, at the 1959 IEEE Electron Devices Meeting in Washington D.C., the biggest technological watershed of all—at least so far as I am concerned. Fairchild had earlier recruited a small number of very able semiconductor men—most from Shockley Transistors—and had begun to make a name for itself in the silicon device business. At this meeting Hoerni presented a paper²⁴ which was eventually to revolutionize not only the semiconductor industry, but indirectly was to have a profound effect on practically every other sector of the electronics industry.

One thing that I remember about the paper was the aesthetically pleasing slides of pear-drop shapes in the violets, blues and greys of the different oxide thicknesses. Many of these shapes on one silicon slice meant that a quantity of these oxide-masked, diffused transistors had been made simultaneously—in other words, mass production methods had now reached the semiconductor industry. Not only that, but after all these oxide-masked diffusions, and the etching of contact holes in the oxides, the surface of the slice was still essentially flat (which certainly wasn't true of the mesa transistor then in vogue) so that aluminium could be deposited on the surface and then etched away to leave contact pads and interconnexion tracks etc.

I am, of course, describing the planar process, although not all of its potential was realized (or revealed) that afternoon. What we did appreciate—as the impact of the paper was analysed in the bars of Washington that evening—was that silicon transistor manufacture would never be the same again. Here was the natural culmination of all the silicon processes then developed and the trick was basically to leave *in situ* the oxide used to mask a previous (base) diffusion—plus the new oxide grown during that diffusion—and then to etch smaller holes through which to diffuse the emitters.

At about the same time, Kilby²⁵ of Texas Instruments was inventing the integrated circuit. Many of us had sketched vague concepts in our laboratory notebooks of pieces of silicon containing more than one component (after all, the p–n–p–n device was basically a true integration

‡ In its own way TI's triumph in controlling and managing its fantastic growth in sales and profits—based as it is on one of the most complex industrial technologies of all time—is no less impressive than Bell Labs' management of research. Both have provided yardsticks by which the performance of their competitors can be measured and have set standards of achievement which few can ever expect to match.

—internally connected—of an n-p-n and a p-n-p transistor), but it was Kilby who first fully appreciated (and patented) the concept of constructing various different devices in one piece of silicon and connecting them together to make a circuit. The real beauty of the situation, however, was that it took Fairchild's planar process to make a commercial reality out of TI's idea, and it was TI's concept of the integrated circuit which really made the Fairchild process of such revolutionary importance.

The story of the rest of the decade can be briefly told.

In the early 60s it was Fairchild which made all the running. Various families of i.c.s began trickling (yields were still very low) off their production lines—r.t.l., d.t.l., c.m.l.—while the rest of the semiconductor industry in the United States made a lot of noise but produced very little. Outside the US—with just two or three honourable exceptions—there was a serious failure to recognize the vast potential of this new technology. Although I had no direct experience of Japan at that time, the bulk of the European semiconductor laboratories which I visited in the early 60s were either trying to leapfrog the Americans on the back of some irrelevant non-planar technology (favourites were the thin-film transistor and the tunnel diode) or were effectively ignoring altogether the development of integrated circuits.

However, it is fair to say that many excellent individuals in Europe knew the (technical) score and were frustrated at the slow rate of commitment of their companies, thus accelerating the 'brain drain' which was such a feature, in the UK especially, in those days. Unfortunately, the early markets for i.c.s were predominantly in the US (i.e. military and computers) and, to this extent, the European companies were fully justified in not making too early a commitment to the production of i.c.s. However, as important markets for i.c.s have developed in areas in which Europe (and Japan) is on a par with, or ahead of the US (e.g. consumer electronics, industrial control, telecommunications), the early failure to develop momentum in the complex i.c. sector has meant that many non-American semiconductor companies find it very difficult to match the production costs and fast technological foot-work of their American competitors.

Probably the best example of this strength of the American semiconductor industry was the introduction by TI in 1966 of a new family of i.c.s, the 74 series of t.t.l. circuits. In terms of absolute management commitment, design skill and marketing acumen the success story of the 74 series is, in my view, unmatched in the history of the semiconductor industry. Within about two years of its introduction it was almost impossible for those of us† making other i.c. families to sell our products into new systems—everybody wanted to (and did) use TI's t.t.l., and gradually most of the i.c. companies came to accept the inevitable and began to second-source the 74 series.

In 1963 an event took place which eventually proved

to be of cataclysmic importance to the i.c. industry and its customers. Considerable work was, of course, being carried out on the properties of semiconductor surfaces and, more or less in parallel, various laboratories were working on types of field-effect transistors, including the well-known work of Weimer²⁶ on CdS thin-film devices. In 1963, however, Hofstein and Hyman²⁷ published the definitive paper on metal-oxide-semiconductor field-effect devices, from which starting point the entire m.o.s. business can be traced.

What they showed—boiled down to its essentials—was that it is possible to use an electric field, applied across the thin surface oxide of a silicon device, to radically alter the conductivity of the thin surface layer of silicon immediately beneath the oxide. In this way a majority-carrier, voltage-controlled device becomes feasible—similar in certain of its characteristics to the thermionic valve, and radically different from the minority-carrier, current-controlled bipolar transistor.

There was, as might be expected, much scepticism about this new device. We still didn't understand oxides or surfaces well enough; circuit designers were used to and reasonably satisfied with the well-established bipolar transistor; and, most damaging of all, it was argued that the intrinsic interelectrode capacitances of the device (gate overlap, substrate-to-source etc.) would always restrict its operation to low frequencies. The device had, however, two theoretical assets of enormous importance if they could be translated into practical terms. First, the m.o.s. transistor was considerably simpler and smaller than the bipolar transistor and, in the complex semiconductor processing sequence, in which the yield loss is directly related to both device size and the number of processing steps, this could imply an important reduction in production costs. Second, unlike the bipolar transistor, it was not necessary to electrically isolate each m.o.s. transistor from its neighbours; this implied that packing densities in m.o.s. integrated circuits could be considerably higher than in bipolar i.c.s, giving the possibility of chips of higher functional complexity and/or lower cost.

The promise of the device was so great, indeed, that an accelerating amount of R & D effort went into trying to solve its many problems. It was soon shown, for example, that with a good gate alignment technique high cut-off frequencies could be obtained;²⁸ considerable work went into removing ionized impurities in the oxide—since these tended to drift under the influence of the gate field and to destabilize the Si:SiO₂ interface, on which so much depended;²⁹ and elegant methods for using the m.o.s. device in complex systems (especially in memory circuits) were gradually evolved.

Nevertheless, there were many who didn't believe that m.o.s. would ever amount to much, and it is interesting to reflect on the fact that the established leaders of the i.c. industry (by the late 1960s these were TI, Motorola, Fairchild, National, Signetics etc.) were generally cautious in their attitudes to the new technology. This is, of course, entirely explicable in light of the enormous commitments which companies such as these had already made to bipolar production capabilities.

† By this time I was General Manager of Elliott-Automation Microelectronics Ltd., centred in Glenrothes, Scotland.

But most of the early running in the m.o.s. field was made—once again—by the small and swift-of-foot innovators, prominent among them American Microsystems, Intel (a new venture by a few of the original key founders of Fairchild), Mostek, General Instrument etc. In any event, the decade ended with planar processing universally accepted and with the relatively simpler m.o.s. technology beginning to challenge bipolar in many i.c. applications, especially those where speed was not at a premium, but cost was.

The State of the Art: Memories are made of M.O.S.

To bring the i.c. story up to date, the last five years or so have not, in my view, brought any major new revolutions or technical watersheds; rather, progress has been evolutionary, with the gradual refinement of both bipolar and m.o.s. technologies and apparently inexorable progress in improving the performance and reducing the costs of integrated circuits.

The 1960s were quite clearly the decade in which bipolar logic i.c.s came to maturity primarily through the rapid growth of their use in data processing systems. The present decade, on the other hand, is already (and in my view will continue to be) characterized principally by the rapid encroachment of i.c.s (mainly m.o.s.) into many memory applications.[†] It is probable that real respectability finally came to m.o.s. technology with Intel's announcement—and subsequent volume production—of the first 1-kbit random access memory. This 1103 device, in my opinion, had the massive, dual impact of bringing widespread acceptability to both m.o.s. technology and to the use of semiconductor memory and must surely rank, therefore, as a major milestone in the accelerating flow of integrated circuit development.

The other major characteristic of the last five years has been the total domination by m.o.s. of the explosive new markets in areas which are often categorized generically as pervasive electronics—that is, population-related (rather than industry-related) markets such as hand-held calculators and electronic watches. It was, needless to say, very much a chicken-and-egg situation. Given a complex but cheap calculator chip, the cost of the electronic calculator was bound to tumble to the point where it would become a 'consumer' product; and given such a massive potential market (for what is essentially just one type of i.c.) the huge investment in design and production capacity was bound to result in a product which could be made in enormous quantities at a very low cost. It was primarily Rockwell which pioneered its way by this means into a position of dominance in pervasive m.o.s. products.

There is really no better example of the overall merits of m.o.s. than the story of the electronic calculator, although the same sort of thing will certainly happen, in

my opinion, in similar pervasive i.c. applications (timing circuits, automotive electronics etc.). Moreover, m.o.s. technology is by no means standing still. New techniques are constantly being developed to extend the speed, power and functional complexity of m.o.s. i.c.s. Complementary m.o.s. (c.m.o.s.), in which RCA, Motorola and National are currently providing a lead, is particularly promising in applications requiring low power consumption, high noise immunity and insensitivity to supply voltage variations.

Meanwhile, of course, bipolar technology has also certainly not been standing still. New, elegant bipolar processes such as isoplanar, and simplified processes such as c.d.i. (collected diffused isolation) have been put into production, although have not yet enjoyed a major market acceptance. One problem is that although the simplified processes certainly reduce costs, they also degrade many performance parameters to the point where m.o.s. products become competitive. In two areas, however, bipolar has made further impressive gains in performance and enjoys essentially complete supremacy over m.o.s. These are in all high-speed logic systems, where e.c.l. (emitter coupled logic) reigns supreme, and in many linear applications (e.g. television and radio circuits, operational amplifiers).

An excellent example of the state of the art in complex linear i.c.s is shown in Fig. 1, which is a chip photomicrograph of the Plessey WR3A logarithmic multiplier, a sophisticated monolithic bipolar design for achieving high-accuracy multiplication with particularly good linearity.

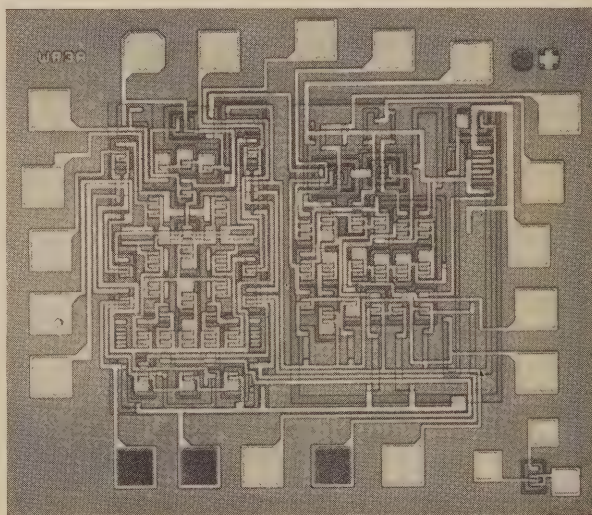


Fig. 1. Photomicrograph of Plessey WR3A logarithmic multiplier chip. (One of the great difficulties in writing about i.c.s is the inevitability of including chip photomicrographs. By way of apology, although this and subsequent photomicrographs may all look similar to the layman, they do have considerable significance for the expert.)

Recently the bipolar case has been considerably strengthened by the development³⁰ of integrated injection logic (I²L), which appears to be particularly promising

[†] So far the take-over by i.c.s of both main-frame and peripheral memory has been largely as predicted four years ago in a major study of UK Microelectronics carried out by the author's consultancy company for the Department of Trade and Industry and the National Research Development Corporation.

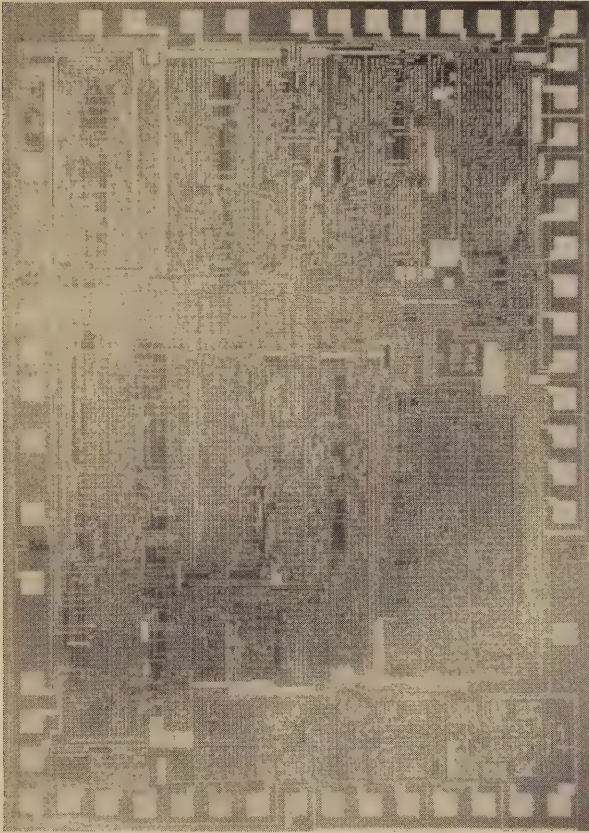


Fig. 2. Chip photograph of Pye I²L decoder circuit.

in certain linear applications and where the speed/power ratio is the performance parameter of greatest significance. An interesting example of an I²L circuit is shown in Fig. 2, which represents an l.s.i. chip from Pye Telecommunications (Philips). This decoder circuit for a national paging system contains about 1000 logic gates and eight isolated linear circuits and is an excellent current example of an I²L product in a commercial application.

The overall question of m.o.s. versus bipolar has recently been debated with great skill and in considerable detail.³¹ To declare my interest, so to speak, I am reasonably well known in some quarters (indeed, infamous in a few) for my prolonged and enthusiastic advocacy of the merits of m.o.s. In fact, apart from applications demanding the highest possible speeds—where I believe that e.c.l. or a similar derivative will hold sway for a long time yet—I have until recently held the view that m.o.s. would gradually increase its penetration of the total i.c. market, leading to essentially complete domination by the 1980s. However, it is now clear that I²L offers some very significant potential advantages, and at this point in time it is very much an open question how much it will influence the momentum of m.o.s.

The state of the art in other parts of the world of semiconductor devices has also, needless to say, been constantly advancing, and I have chosen just two examples, from opposite ends of the power/frequency

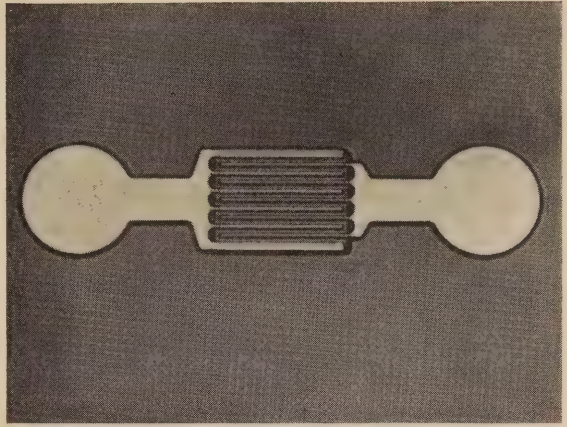


Fig. 3. Developmental Fairchild microwave bipolar transistor with 1 μ m emitter stripes.

spectrum, to represent the impressive improvements which have occurred, and which attract relatively little notice compared with the blaze of publicity given to i.c.s. The first (Fig. 3) is a developmental microwave bipolar transistor made by Fairchild using an ion-implanted base. The device has 1 μ m emitter stripes and the gold metallization pattern consists of interdigitated 1 μ m lines and spaces, giving $F_{\min} = 3$ dB and associated gain of 9 dB at 4 GHz. To try again to put things in perspective, it is worthwhile pointing out that twelve years ago²⁸ it was just about possible, using electron beam resist exposure techniques in a research laboratory, to produce individual 1 μ m wide metallization stripes on a uniformly-oxidized slice of silicon, i.e. with no correlation with any actual diffused structures. Now Fairchild have developed a microwave transistor the performance of which is predicated on the ability to reproduce in a production environment a structure containing ten 1 μ m stripes at 1 μ m spacing.

The other example is from the realm of high-power semiconductor devices which, although also manufactured from silicon, have almost nothing else in common with i.c.s except for considerable economic significance. This device, the B.St R 68 thyristor (Fig. 4) is a recent Siemens development, and it has been specifically designed for applications in high-voltage d.c. transmission systems as is best illustrated by its impressive peak reverse voltage of 3200 V. As the first man to my knowledge ever to observe and understand the thyristor d.c. characteristics, and as one who spent several years involved in diffusion techniques aimed at higher and higher junction break-down voltages, all I can say is that this device would in my era have been unbelievable and even today is quite extraordinary.

The Way Ahead: More for the Money

Although spanning only a brief period of time, the story of semiconductor devices has been rich in scientific achievement and economic significance and in triumphs and failures of managements and men. But it is far from over. In my view there lie ahead many more fascinating decades of technological confrontations and management drama, but it is only possible in the space remaining



Fig. 4. Siemens 3200V BStR68 Thyristor.

to give a brief outline of how I believe things may develop. Moreover, I shall deal only with i.c.s in this final section—not only because of space limitations but also because the i.c. sector will continue to dominate the semiconductor industry in terms of economic significance and technological volatility.

My task here is relatively simple since it is only about two years ago that I was invited to review the main trends affecting the future structure of the semiconductor industry in the special issue of this Journal celebrating the 25th anniversary of the transistor,³² and I intend to make extensive reference to that paper in what follows.

To deal first with *technological trends*, in my view, the following are the salient factors relating to future developments in the field of i.c.s:

There is no possibility in the next decade of a significant displacement of silicon by any other type of semiconductor.

The principal processing will continue to be based on a combination of diffusion and photolithography, although new techniques (e.g. ion implantation, electron beams, projection printing, silicon-on-sapphire substrates (s.o.s.) etc.) will continue to be developed.

The bulk of i.c.s in 1980 will clearly resemble those made today, although chips will contain more devices and will be more densely packed.

So far as *product trends* are concerned, there are, heaven knows, enough contenders. Just for the record we have, *inter alia*, t.t.l. S/t.t.l. (t.t.l. using Schottky barrier input diodes), e.c.l., p-m.o.s. (m.o.s. circuits with p-type channels), n-m.o.s., c.m.o.s., s.o.s., c.c.d. (charge-coupled devices), I²L and then a host of secondary classifications by technology, such as silicon gate and metal gate, isoplanar and c.d.i., ion implantation etc. To give detailed forecasts, and the justifications for them, in such a complex situation is obviously not possible in

a brief review paper. I must content myself, therefore, with a few brief but broad statements of my own views.

First, I believe that the generic family of m.o.s. devices and derivatives will continue to capture an ever-increasing fraction of the total i.c. market. The products on which this penetration will be based will primarily be consumer-oriented plus memory systems for both data processing and telecommunications equipments, and the most important associated technologies will be c.m.o.s., n-m.o.s. and c.c.d. In memory applications, it is my view that there will be two major strands to the market advance. The first will be in the 'classical' r.o.m., p.r.o.m. and r.a.m. areas in the last of which (see Fig. 5) it has been confidently predicted³³ that circuits of 64-k bit complexity will be commercially available within about three years.

The second major impact will be when c.c.d. serial memories (which are basically a very simple form of m.o.s.) become competitive with magnetic disk and drum storage for very large mass-memory systems. A major recent advance in this direction has been Intel's announcement of its 16-kbit c.c.d. memory (part number 2416), a chip photomicrograph of which is shown in Fig. 6. This device, in my own strongly held opinion, presages the real

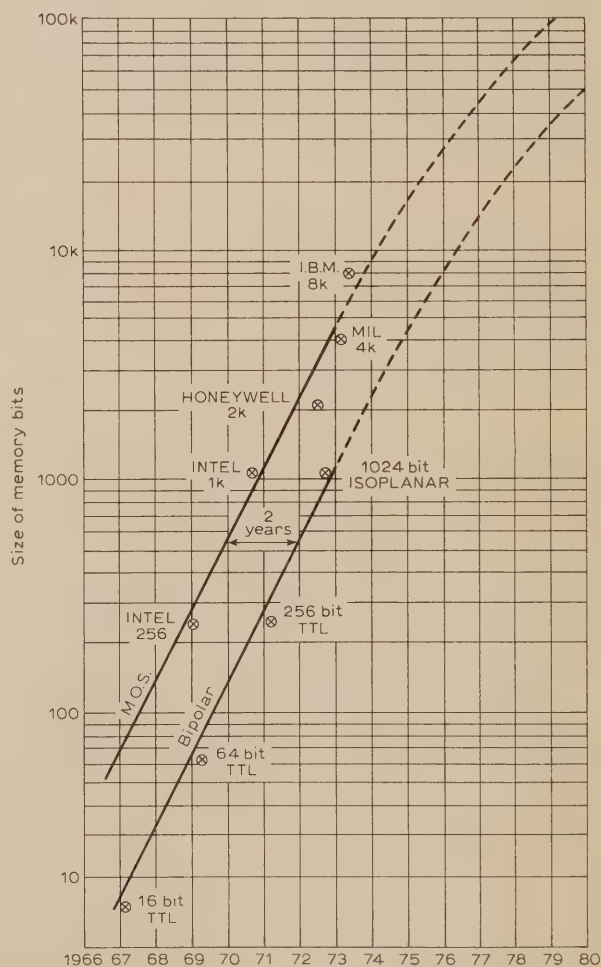


Fig. 5. Historical and forecast development of bipolar and m.o.s. r.a.m. complexities.

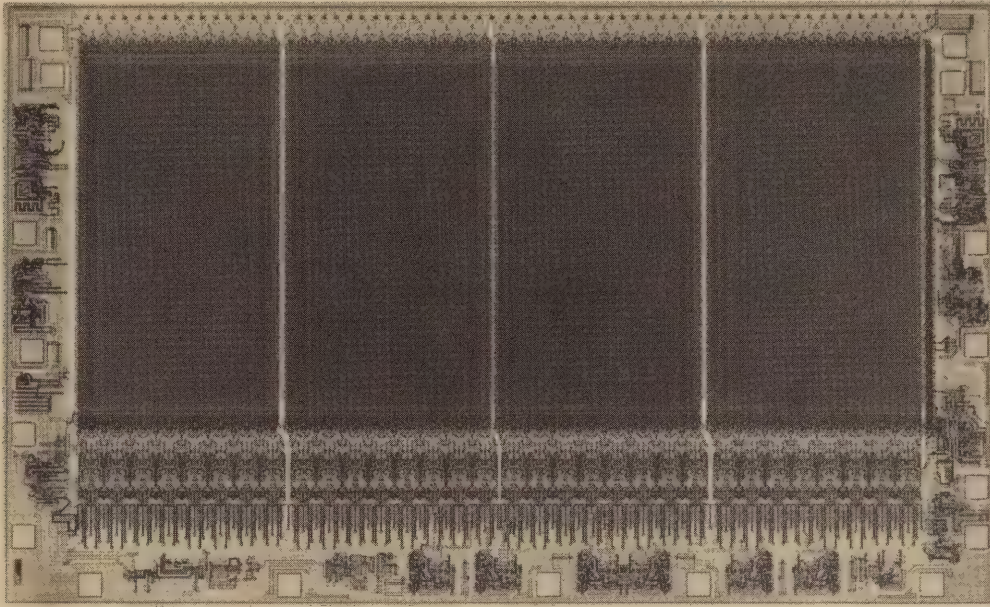


Fig. 6. Chip photomicrograph of Intel 2416 16-kbit c.c.d. memory. It is interesting to note that individual devices are really too small to be resolved in this photograph.

beginning of the onslaught of semiconductor technology on the markets currently held by 'rotating' magnetic memories.

Of the other (bipolar) products, to simplify outrageously an enormously complex issue, I believe on the basis of currently-available evidence that t.t.l. (and derivatives) will continue as the work-horse of logic systems over at least the next five years, that e.c.l.-type i.c.s will steadily increase their market share (centred predominantly on high-speed logic systems), and that I²L will be particularly successful in applications where packing density and the speed:power ratio are of major importance.

Overall, there is also certain to be a substantial increase in the development of a wide variety of systems based on off-the-shelf combinations of microprocessors and associated memory (including programmable memory). The microprocessor represents one of the most important standard l.s.i. circuits of the future although, in my view, its importance to the i.c. manufacturers will be as much for the 'add-on' memory i.c.s which its use entails as for its own intrinsic sales value.

So far as *market* and *economic trends* are concerned, since they are really outside the scope of this essay, I would refer interested readers to my earlier review paper.³² Regarding the *structure of the industry*, however, it may perhaps be worthwhile to reprint here two brief excerpts from that 1973 paper:

'In general, the overall structure of the US industry, and the general nature of the forces acting on it, are not likely to change drastically over the decade. There will still be cycles of famine and glut, under-capacity and over-production. New price wars will flare up and lead to the collapse of the most tenuous participants, and the gradual evolution of new technologies and new products will give continuing but

fewer opportunities for newcomers to challenge the established companies.'

'Clearly much needs to be done, by both European governments and industrialists, to foster the development of i.c. companies which possess the right combination of determination to succeed, financial 'muscle-power' and willingness to learn what it takes to succeed in this difficult industry. Only when effective actions are taken by such companies to work out and put into effect new strategies relevant to the 1970s, will it be possible to predict with any confidence the eventual emergence of viable and competitive European participants in the integrated circuits industry.'

Finally, I wish to submit that in general terms the way ahead for integrated circuits is quite simple to predict (the tricky bit, of course, is forecasting the all-important details). There will be a continuation of the trend whereby R & D *per se* is becoming of less relative importance whereas essentially commercial considerations (e.g. product marketing strategies, production investment decisions, market research etc.) are becoming increasingly vital aspects for survival and success. Nevertheless, the industry will undoubtedly continue to develop ever more complex chips, providing new and enhanced electronic functions at progressively lower costs. The cost savings which become possible through the use of i.c.s will not only continue to reduce the prices of well-established electronic products such as data terminals, word processors etc., but will also lead to an acceleration of the trend towards carrying out electronically various operations in sectors such as telecommunications and business systems which have historically been performed by electro-mechanical techniques.

And let me end, quite finally, with just two more predictions. The first is that when the Centenary Issue of this Journal is published in 2025 the subject of Semi-

conductor Devices will still be so important and so topical that the Editor will again insist on its inclusion as a major topic for a review paper. Although I certainly won't be around by then I would like to think that the invited author might possibly look up this paper to get a feel for what we thought about these delightful devices all those years ago, and also perhaps to see if it is possible to meet the Editor's (impossible!) requirements about style and length. My second and final prediction is that he will have just as much trouble with getting his paper right as I have with mine!

Acknowledgments

Thanks are due to the following individuals and companies for permission to reproduce the chip photographs used in this paper: W. Holt, Plessey (Fig. 1), A. K. Sharpe, Pye Telecommunications (Fig. 2), J. Archer, Fairchild (Fig. 3), L. Hofman, Siemens (Fig. 4) and G. E. Moore, Intel (Fig. 6). In addition, helpful comments were made by D. H. Roberts during the preparation of the paper for which the author wishes to express his gratitude.

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The Education of Professional Electronic Engineers

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The purpose of university education in electronics is discussed in the light of the requirements of industry. The role of postgraduate experience courses is considered, particular reference being made to the problems which the Bosworth scheme encountered.

Introduction

Nowadays the younger professional worker in electronics is likely to have completed his education by obtaining a first degree at a university, polytechnic, or other similar institution of higher education. The discipline of study is almost certain to be one or a combination of the following: electrical, electronic, control and/or telecommunication engineering, electronic science, pure and/or applied physics, computer science. Most of these disciplines have areas of common subject material and courses in these subjects feed a significant fraction of their graduates into the electronics industry. Here I use the term 'electronics' in a generic sense to include telecommunications, computer systems, light-current control systems and electronic instrumentation systems.

Many of the graduates of physics and science-orientated courses go on in their professional careers to study the physics of devices. The latter may be important components of electronic systems. Some may become involved in the development of devices or even the generation of new types of device. These persons are not in general concerned with overall system aspects and, in this respect, may not be classed as engineers. Nevertheless a significant fraction of the electronics industry is engaged in component work and the line between development scientists and electronic engineers is hard to draw in a definitive way. I am inclined to include all such persons under the umbrella title of professional electronic engineers and my remarks on education refer equally to all.

The ranks of professional electronic engineers have not always been filled from the output of degree-type courses. Many of the degree courses which now feed the industry did not exist ten to fifteen years ago. Then

many professional electronic engineers were drawn from electrical engineering and physics courses which contained little or no electronic or telecommunication content. Many others had arrived through the then all-important, part-time, Higher-National-Certificate route of education. The technological developments in electronics, particularly over the last five decades, have put demands on the education of potential electronic engineers which cannot be met by the previous *ad hoc* routes. Out of this has grown the academic discipline of electronics which, with various emphases, now forms the basis of numerous degree-type courses for the education of electronic engineers. The department of which I am now a member was the first university department of electronics in the United Kingdom and was inaugurated by Professor Eric Zepler, a past president of the Institution, in 1947. Since that time, electronics science, electronic engineering and related degree courses have been established in most British universities and polytechnics.

The Influence of the IERE

The role of the Institution of Electronic and Radio Engineers in the development of electronics education cannot be overemphasized. It actively promoted the need for a proper balance of subjects, particularly between heavy-electrical engineering and electronics, in educational training schemes. It must be appreciated that there was considerable reaction to this activity from the established profession of electrical engineers which in years past apparently held the corporate opinion that telecommunications and electronics were but minor branches of electrical engineering: 'after all, it is all governed by Maxwell's equations'. In particular, way back in the nineteen-fifties and early 'sixties, the IERE, through the medium of its education and examination committees, did much to influence the developing pattern of electronics education, not least through Section B of the graduateship examination. The latter became an internationally recognized academic standard for radio and electronic engineers overseas. At the anecdote level, *circa* 1960, I well remember one of my colleagues on the examination committee proclaiming explosively, in response to traditional reaction, 'we want our graduates to be able to shin-up aerial masts not drive trams'.

Subsequently the IERE significantly influenced both the nature, subject range and subject content of the examinations of the Council of Engineering Institutions. Without

Professor K. G. Nichols (Fellow 1967, Member 1960) was appointed to a chair in electronics at the University of Southampton in April 1974. After graduating from the University of London he held industrial and technical college appointments before going to Southampton as a lecturer in 1961; he was appointed to a readership in 1970. Professor Nichols has been a member of the Council of the Institution since 1973 and he has served on the Education and Training Committee for several years as well as on the organizing committees for national and regional conferences. He recently spent a year as IBM Fellow at the Hursley Park Research Laboratories. He has contributed numerous papers to this and other journals, and is author or joint author of three books.

this influence there is no doubt that the CEI scheme would have been much less suited to education of electronic engineers. While not possibly obtaining the optimum scheme, the inclusion of the optional electronics subject in Part 1 and the provision for several electronics-based subjects in Part 2 were obtained largely through the influence of the IERE. The retention of some part-time route, however tenuous, to the ranks of professional engineering was achieved by a small group of institutions which included the IERE.

The Purpose of an Electronics Education

To set in print my ideas on this subject, I am well aware, could be foolhardy and it is with considerable misgivings that I attempt to do so. Many excellent papers on the topic by noted educationalists have appeared over the years and most of the significant comments have already appeared in them. One of the more recent forums¹ on education for professional electronic engineers was held at the University of Hull in 1973. For a full and informed discussion on the subject I commend the reader to the proceedings of this conference. In this short essay I cannot hope to achieve the same breadth and depth of treatment. In the conference, Professor Geoffrey Sims² in an appendix to his paper listed six desirable aims to be satisfied by a vocationally-oriented university course. These aims are given in the adjoining Table. Others have stated essentially the same requirements in other ways. Few would disagree with their sentiment. They form a cogent set of aims from which derive further requirements. Indeed, the six aims are, of course, here quoted out of context; in the source paper the whole is developed and qualified.

Aims of a vocationally-orientated university course

- (a) To develop a critical approach to the solution of scientific problems of any nature.
- (b) To develop the student's capacity to learn by his own resources.
- (c) To provide a sound knowledge of the scientific principles underlying any chosen field of technology.
- (d) To provide, in more detail, over a more restricted field, some knowledge of current practice—including design at a suitably advanced level.
- (e) To introduce the student to the sociological implications of his work.
- (f) To develop the latent individual character of the student.

For the present I will accept that these are the aims and assume that the only problem is how to satisfy them. Later, I will return to question and qualify some of the implications they contain.

I am not only possibly foolhardy in putting my ideas in print because of the danger of plagiarism but also because they may seem absurd to all the other experts on education, namely, every other professional electronic engineer. Every member of the profession qualifies as an expert on education as a result of direct personal experience of the process. Younger members will have

had the experience at the hands of others while for older members like myself the experience was self-inflicted. My own academic background was in physics and mathematics and I naively assumed that my subsequent self-acquired knowledge of electronics over a period of three to four years would be adequate to follow a career in the profession. I noted, but only just, the invention of the transistor in 1948 and mentally catalogued it as a novel but unimportant device. The shockwave of this device swept me away sometime in the nineteen-fifties and I have been largely submerged under the tide of new development ever since. Throughout this period I have earned my living as a teacher of electronics and my principal problem has been one of self-education: 'Can I understand it in time to explain it to the boys next week?' has been my main priority. Of course, I exaggerate slightly, but not so much, from the truth and I hate to think what my success rate with explanations-to-the-boys has been! Mature consideration of appropriate course structuring and content has by necessity been assigned a lesser priority. The word 'mature' is the keyword; in maturing, the subject develops and course structure and content can become obsolete.

The time of expansion is ending and the subject is moving on to a plateau. I have heard this many times in the last decade and on occasions even believed it myself. Nevertheless the technological development accelerates rather than abates. New developments in established areas continue and new concepts open up new areas of electronics. Planar technology and integrated-circuit development continues as an established area, for example, while charge-coupled devices introduce new concepts yet linked to the established technology area. These developments are partially responsible for the rapid advance of large-scale-integrated (l.s.i.) circuits which in turn are causing revolutionary changes elsewhere in electronics. Digital data processing systems in general and the interface between software and hardware engineering in particular have been affected by the l.s.i. developments. This applies also to communication engineering, traditionally analogue, which is rapidly becoming 'digitized'. The continuing progress being made in quantum electronics, non-linear optics, and optical fibre systems is also going to have a profound effect on communication systems. The increasing interaction between integrated-circuit technology and opto-electronics is a part of this progress which, in its turn, will influence future digital-data processing systems. Each development seems to influence almost all areas of electronics. To this extent the subject of electronics is now more cohesive than in the past.

One of the side effects of the electronics renaissance is the unique requirements it puts on an electronics education in relation to that for other engineering disciplines. Of necessity it is more vocational. Not only is the new graduate electronic engineer often expected to bring new ideas and knowledge through to his employment, but he is also often expected to be a fully-fledged professional engineer. In more traditional engineering disciplines, the new graduate engineer would normally serve as an 'apprentice' to a more experienced engineer

for some years before being adjudged professionally competent. I am frequently surprised to see our ex-students presenting, as experts, papers at learned conferences as little as two years from graduation.

The passage of time has shown the inadequacy of both the fundamental and vocational content of many electronics courses. Fortunately, electronics has always attracted very able students and I suspect that they survive and flourish in their employment more because of their intellectual ability than because of their education. We must face the possible situation that as other disciplines become more challenging and attractive, we may not in future continue to attract such able students to our profession.

It is against the background described in these last paragraphs that the six desirable aims of the vocationally-orientated course must be viewed. The principal dichotomy facing the course planner occurs between the immediate vocational requirements of the course and the need to engender an ability to understand new concepts and develop them as engineering applications. It might be thought that the ability to deal with new concepts implies the need for a basic core of physical and engineering principles in any degree course. This may be so, but I am inclined to think not; I contend that the fundamental principles underlying any chosen field of technology are constantly changing, albeit possibly slowly. The fundamental or axiomatic principles may be invariant but the engineering-level principles develop with the subject. Thus while I accept aim (c) I feel its implementation is inordinately difficult and critically dependent on current technological assessments made by the teaching body.³

I also have reservations concerning the value of aim (d) or rather, any attempt to meet it in the academic part of a degree course. It has been suggested that professional training has little place in a college course. I subscribe to this view on the grounds that the college staff are unlikely to be adequately qualified to accomplish the full-range of the task. Nevertheless, aim (d) is an important one and all engineering degree courses should contain an element to achieve it. In my view the college-industry sandwich degree schemes are most suited to this purpose and I would propose that continuing effort to promote these schemes should be made until they become the predominant route for entry into the electronic profession.

The sociological aspects of engineering, aim (e), and its future development are indeed important. Within the framework of an engineering education, every endeavour should be made to make the potential engineer aware of the sociological implications of his potential work. The subject is however highly emotive and empirical with not the least part of the problem being the chasm which exists between technologists and non-technologists. While some formal part of an engineering course should be devoted to its study, the real answer lies in encouraging much greater participation by engineering students in community activities both within and without the college. The present high-intensity vocational courses allow little time for such

activities and should be altered to reduce the course-time commitment of students to that for non-technological disciplines. Further to this, greater participation by professional engineers in community interests such as politics, local government (planning, communication, conservation, etc.), trade unions, and even in other areas of employment (farming, distribution, etc.) is very necessary and requires active encouragement.

The development of latent individual character, aim (f), may be difficult to achieve within a planned course. It could well be that participation in sport or drama or that liaison with another person is just as likely to stimulate character development. In some cases character facets may not appear until responsibilities of employment or parenthood are encountered. It is unlikely that teachers of engineering in a college would know how to, or would wish to, make specific efforts in this direction although they might well cause incidental developments.

I refer finally to aim (a), which is an ideal difficult to meet in practice. Few professional electronic engineers could adopt a *constructive* critical approach to the solution of scientific problems of *any* nature but many might be able to do so for a restricted class of problems. The average human brain is capable of deductive logic only in infinitesimally-small steps from a base point established in previous experience. Fortunately this is the nature of reasoning required of all but a very small part of professional engineering, much of which is of a very routine nature and requires a logical, systematic, approach. The significant advances are made by the very small minority of geniuses or near geniuses who are capable of making inspired guesses or finite-step logical deductions. Provided either they, or others, can explain their advances in simple small steps all is well. I would therefore restrict aim (a) to:

'To develop a critical approach to the solution of problems based on the scientific principles underlying the chosen field of technology.'

An additional aim might be framed as

'An awareness of problem-solving techniques in related areas.'

The Role of the Teacher

One role of the teacher is to identify the principles underlying the chosen area of technology, in our case electronics, as they are currently established and, optimistically, as they will be in the future.³ Personally, I doubt if the latter can be achieved with any reliability by individual, or corporate bodies of, teachers. A second role is to marshal these principles in a logical and cogent manner for ease of assimilation by the students: not too much so though or else they pass to the student without the latter giving them any critical appraisal at all. A third role is to show students how to apply those principles in real engineering situations. Given that this application area can be taught effectively, which usually means that the student is taught to teach himself, a significant part of the education then becomes independent of any particular set of fundamental principles. The need for future re-education, either by course or

self-instruction, to cover shifts of principles or changes of technology could thus effectively be minimized.

The difficulty is to establish current principles and, more problematically, future trends. It is necessary to be wary of the vociferous proponent of a new concept or idea or of the proponent of a 'unified' approach. Current examples of the nature of the problem are the programming language APL⁴ viewed almost as a 'faith' by its proponents, graph-theoretics⁵ as a unified approach covering a wide variety of areas, and the algorithmic-state-machine (ASM) chart⁶ method of logic-system design. I will not commit myself as to which of these examples I think significant but simply point out that the corporate body of teachers responsible for a course has to evaluate such developments, try to discriminate against pure fashion, but yet retain true developments of principle. A similar danger is presented by the exceptionally well-written text-book which slowly develops over many chapters a subject area of minority importance to the course as a whole. The teacher has to evaluate the relative importance of the topic, sift the detail for salient points, and eliminate unnecessary overlap with other areas of the subject. It is very easy to become intoxicated and carried away by well-written text-books, particularly if fashionable in the sense of the earlier part of this paragraph.

Postgraduate Experience Courses

In an expanding subject like electronics there is little doubt that the principles underlying the subject shift in emphasis and even change with time. There is a definite need for re-education or re-training on at least one occasion after graduating. In many instances this is accomplished by the professional engineer himself as a result of interaction with other professional engineers, with young graduate engineers, and by technical conferences and publications. Where the developments are radical or where the engineer has been totally committed to a particular project for some years, self re-education may not be effective and the use of college-based courses may be essential.

Following the publication of the Bosworth report⁷ a number of vocational courses closely linked with identified industries were established.^{8,9,10} These courses were intended either to 'professionalize' new graduates or to re-orientate 'obsolescent' professional engineers, sometimes in the same course! Considerable care and effort expended in the organization and running of these courses has not, in general, prevented their collapse. Objective evidence of the real reasons for their collapse is difficult to find in the literature although the evident mode is a short-fall of students. Recruitment fell at one time with the general recession in the electronics industry but has not recovered with the apparent recovery of that industry. Most of these schemes and courses were publicized extensively at birth by papers at conferences and in journals. It is a pity that their demise has been allowed to pass virtually unnoticed; critical analysis of their collapse could have provided useful information.

The concept behind a 'Bosworth' course was to

provide for new graduates a period of vocational instruction and training oriented towards a specific industry while yet related to an academic discipline. This required a close partnership between an academic institution and the appropriate sector of the industry. Academic instruction was to be carefully integrated with vocational training in an industrial establishment. Courses of this nature developed with goodwill and very considerable effort from both sides of the partnership. The Engineering Industries Training Board and Science Research Council underwrote a significant part of the very considerable expense involved in setting up and running of the courses, but even so industrial concerns who sponsored students on the courses were expected to make some contribution to the expense.

There is no doubt that educationally these courses could be deemed successful; many ex-students now hold important posts in the relevant industries. Nevertheless, the courses did collapse. Among the complex reasons for this are the following.¹¹ Firstly they were largely incompatible with the structure of professional training arrangements as they exist and are operated by personnel departments in industrial organizations. The latter, with good reason, are reluctant to support unproven new graduates especially when they have been only marginally involved with their selection. The normal industrial practice is not to select any man for special treatment until he has been in the firm for at least a year or two during which time his potential usefulness is established. Secondly, the sponsorship of a student on a 'Bosworth' course involves a firm in a new type of expenditure unprovided for in the traditional financial provisions for training bearing in mind the attitude sometimes expressed that education should be paid for by the Government.

The function of a postgraduate retraining scheme may be to acquaint an engineer with new developments in the academic discipline or to provide academically related vocational instruction. It is arguable whether the latter can be properly provided in an academic institution or whether it should be provided by the industrial organization itself. Where a firm is entering a new area of development it is possible that an academic institution can be useful in this way. Again most of these schemes have collapsed or have had only limited success. A critical factor¹¹ in such schemes is the course duration. If too short, a week or so, they are little more than specialist-subject conferences; if too long, six months to a year, firms are reluctant to send key men on the courses. Less able men are unlikely to be released on the grounds that the expense is unjustified in view of the limited benefits to the firm. Also, some candidates for the courses fear they may miss promotion or otherwise suffer career degradation if they are absent from their normal work for too long. Experience has shown that the incentive of a higher degree (M.Sc.) is an essential ingredient of the longer duration courses. Even so this introduces its own problems; an engineer of some years' experience may doubt his ability to cope with academic work and the rigours of its assessment by examination or otherwise. He may feel he has much

to lose in career development if his performance on the course is in any way unsatisfactory. At least one such scheme is modular in that a student is required to complete a number of short courses on different occasions to obtain the higher degree. In practice most students complete only one or two modules before withdrawing from the course.

Having met and talked to many professional electronic engineers in industry, I am not convinced that they are able to keep abreast of their subject without formal re-training courses. While large international concerns may be able to provide the necessary courses in house, many other industrial (and teaching!) institutions cannot. The future health and competitiveness of the electronics industry in this country depends on the ability of its professional engineers. Proper re-training for this function in the face of changing technology needs to be given significantly more attention than it is at present.

Conclusions

In this paper I have tried to give a broad overview of the requirements and difficulties of educating professional electronic engineers. I have expressed and attempted to justify the opinion that there is no immutable core of subject material on which an educational course can be built. I have pointed out that while technological forecasting is an important function of the corporate teaching body it is also a very difficult task with traps for the unwary. I have also suggested that although academic institutions need to take cognizance of vocational training requirements, it could well be that the proper place for this is within industry itself. Finally, I have discussed briefly the nature and shortcomings of postgraduate experience courses and stressed the need for further efforts on the part of both academic institutions and industry to ensure that professional engineers are adequately equipped to meet the challenge of the future.

Acknowledgments

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Electronic Components—from valves to integrated circuits

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Components produced pre-war, during wartime, after the war and the current scene are dealt with successively, showing how requirements for equipment were met. Future developments will lie in the full exploitation of microelectronics.

It is difficult to define 'components' precisely. The French used to define them as 'pièces détachées' and the Americans as 'parts'. The 'detached pieces' have now become integrated circuit assemblies consisting of many thousands of individual components. 'Passive' components—resistors, capacitors, etc., and 'active' components—valves, transistors, etc., have now been made for many years but it would be true to say that it was the early 1920s which saw the birth of the 'components' industry. Previous to this, a few manufacturers had made valves, resistors, capacitors, transformers etc., for home construction but when the British Broadcasting Company commenced programme broadcasting on 14th November 1922, the demand for components immediately increased. Valves had been made initially by lamp manufacturers, as the techniques of glass blowing and vacuum processes were similar. Bright emitter valves in rows lit many an enthusiastic amateur's living-room and when these were followed by dull emitters, some of the early magic seemed to disappear. The early dull emitter valves were fragile and expensive and when the filaments broke a period of saving-up was often necessary. Amateur constructors may also remember the pungent smell of ebonite drilled at too high a speed although,

with the introduction of the screened-grid valve in 1924, metal chassis rapidly replaced ebonite panels.

Some typical components of this period are shown in Fig. 1. Resistors were produced in large quantities and used as grid leaks, anode loads etc., and consisted of carbon compositions of many kinds compressed into tubular containers and fitted with end caps. Paper-dielectric capacitors were mainly tubular types enclosed in plain bakelized cardboard tubes, with bitumen or similar material sealing the ends.

Bakelite-enclosed stacked-mica capacitors, fitted with screw terminals and with the bottom of the case sealed with bitumen, were also in common use. Rectangular metal-cased and plastic-cased types were also used. Electrolytic capacitors were mainly wet types in tubular metal cases. Cracked-carbon film-type resistors were introduced from Germany in about 1928 and by 1934 were being manufactured in quantity in this country.

Figure 2 shows front and rear views of the tuner and detector-amplifier circuits of a four-valve receiver built in 1923. Point to point wiring was used between the components. Square section wires were sometimes used with sharp right angle bends to make all the wiring horizontal or vertical, reminiscent of the wiring patterns of some modern multi-layer printed wiring boards. This soon gave way to round wires and the home constructor grew remarkably adept at wiring up such receivers as the Mullard Master Three, Cossor Melody Maker, the Scott-Taggart ST100, etc.

From 1930 onwards the home construction of sets diminished and many component manufacturers and radio set makers worked together. Techniques for component manufacture in quantities improved, and some ten million radio sets were in use in the United Kingdom in 1939. The standard to which components were made were those of domestic radio, the self-compensating action of the radio valve making wide tolerances and poor stability generally acceptable. Apart from certain electrical engineering applications, telephone companies, a few sections of the instrument industry and the Services, no very high standard was required of the component manufacturer. The first step towards improved components was taken in 1938, when the Royal Aircraft Establishment began type-approval tests to Wireless Telegraph (WT) Board Specification K110, on a wide range of components for Air Force use. Directorate of Communications Developments (DCD) specifications

Mr. G. W. A. Dummer (Fellow 1960, Member 1958) has experience in components which goes back continuously for more than 50 years to his activity as a non-transmitting amateur in the early 'twenties. During the 'thirties he was with Mullard Radio Valve Company, A. C. Cossor, and Salford Electrical Instruments, and at the outbreak of war he joined the predecessor of the present Royal Radar Establishment to work on time-base development.

In 1944 he began research and development on components and constructional techniques for radar equipment and in 1945 was made a member of the Radio Components Research and Development Committee (RC/RDC) which placed contracts with industry, universities and research associations for new components and materials. He remained a member of this Committee and served for many years on this and several other governmental and international committees in the field.

In the early 1960s Mr. Dummer initiated the majority of government research on thin-film microelectronics and pioneered work on semiconductor integrated circuits. He was awarded the Wakefield Gold Medal by the Royal Aeronautical Society for this work in 1964.

Mr. Dummer left the RRE in 1966 as Superintendent of Applied Physics to become a full-time author and consultant.

He is the author or co-author of the 'Radio and Electronic Components' series of books and of numerous papers and articles.

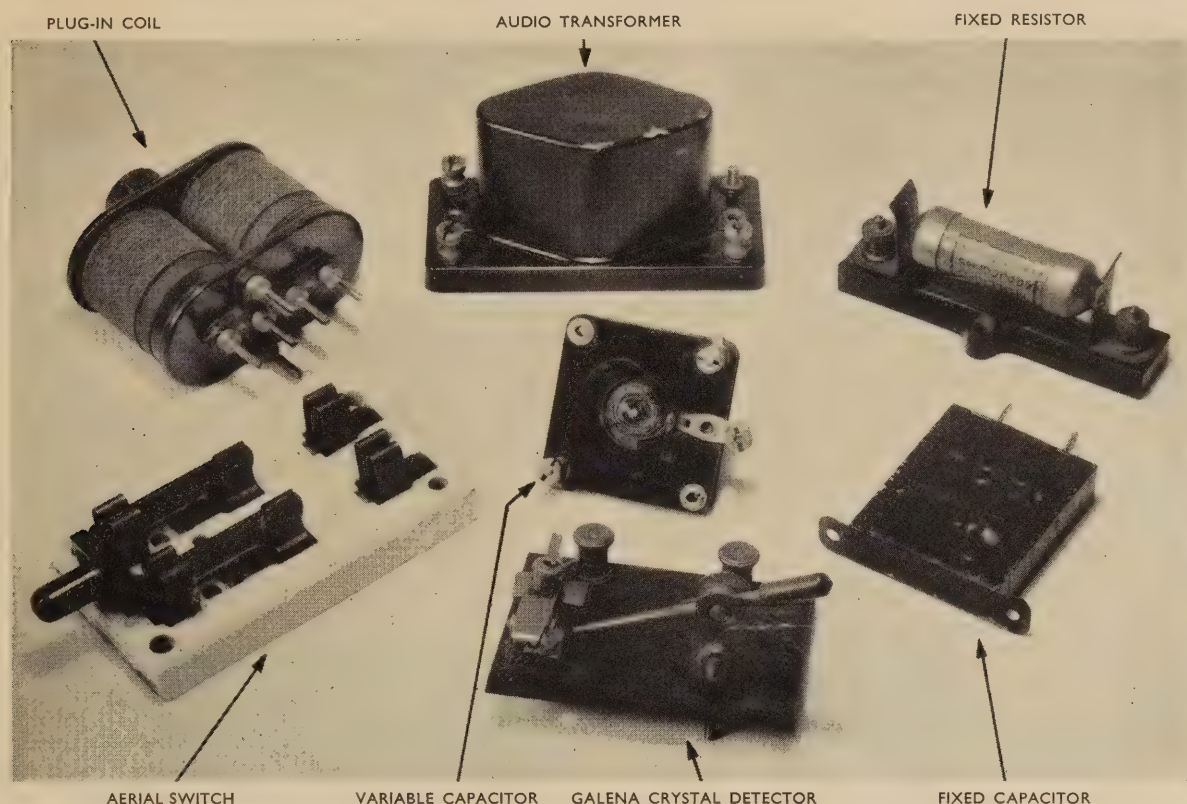


Fig. 1. Typical components of the 1920s.

were drawn up and standard lists of components prepared.

The advent of the 1939–45 war had a tremendous effect on components. Under the stress of war, it became essential to produce large quantities of components quickly. The introduction of radar into the Services meant that still more components including many new types, were required. The need for increased production, which amounted to approximately three times the normal peace-time output, and the shortage of materials, led to Inter-Service rationalization of components, commencing in 1941 with the formation of the Inter-Service Communications Components Committee (ISCC) and followed by the formation of the Inter-Services Component Technical Committee (ISC Tech C) in 1942—later the Radio Components Standardisation Committee (RCSC) and now the BSI Common Standards Committee. An example of the success of this rationalization is that in 1942 there were 1500 different plugs and sockets in use in the Ministry of Aircraft Production alone, and after rationalization only 200 were retained by the three Services. Inter-Services technical specifications for components were also drawn up by ISC Tech. C. These specifications were, and still are, purchasing documents, and present Common Standards specifications (9000 Series) contain the inspecting procedure for accepting components, for type approval and also reliability data.

The requirement for compact mobile equipment, such as man-pack sets and for equipment to fit into small spaces such as in fighter aircraft, led to the development

of miniature components. Valves were reduced in size from conventional to miniature and then to subminiature with standard bases and finally to subminiature with flying lead connexions. Subminiature valves with standard bases went through a difficult period of bad contacts between pins and valve holder, as the pins were made of nickel-iron to match glass expansion and these tarnished rapidly. Passive components such as resistors and capacitors were miniaturized as far as possible consistent with 100 to 300V working. Powers handled were still consistent with valve techniques but size reductions of one half to one quarter were achieved. The phrase 'you cannot miniaturize the watt' represented the position at that time, as the transistor had not yet been invented.

This period saw the emergence of the requirement for higher reliability. Component failures in missiles showed the high cost of unreliability and the failure of a missile costing £10,000 or more, due to a bad contact in a plug and socket costing a few shillings, emphasized the problem. The war effort was now so dependent on electronics that mission losses or even battle defeats could be due to electronics failures.

Although the need for improved reliability was realized during the war, little effort was available until the war had ended. Various committees were set up, but there were no standards of reliability and it was some time before the users (Navy, Army and RAF) stated a requirement for reliability. Even then, the cost of extra testing, component improvements, proving of designs,

higher standard of inspection etc., proved a barrier to definite improvements. It was not until the early 1960s that genuine improvements began to be felt.

Rough handling was inevitable under the pressures of war and both equipments and components had to be designed to withstand wartime shocks and vibrations. Large capacitors mounted by their leads broke off under these conditions and mounting clips were necessary. Transformers held by 4 BA bolts sheared off and larger diameter bolts were used. Valves sprung out of their sockets and retainer clips became necessary. All types of components were, therefore, made more rugged to withstand these conditions.

Some components were to experience severe vibration under war conditions in aircraft, tanks and ships. Considerable work was done to determine the natural resonances of components both mounted and unmounted. Resonant frequencies of small components with lead lengths of 30 mm (1.2 in), wire diameters of

0.6 mm to 1.0 mm (0.025 to 0.042 in) and weights from 0.28 g to 11 g (0.01 to 0.4 oz) were in the range 200 to 450 Hz. With lead lengths reduced to 12.7 mm (0.5 in) resonances were raised to 1000 to 1500 Hz. In some variable resistors the slider could vibrate along the track, changing the resistance and, in addition, the shaft length and knob weight considerably affected the resonant frequency. Variable capacitors became microphonic under vibration. In sealed transformers, the connecting leads from the winding to the inner terminals sometimes fractured when no slack had been left in the connexions. Many improvements in component design and construction resulted from this work.

When equipment such as 'walkie-talkies' had to be operated in arctic conditions, or radar tail-warning equipment in high-flying aircraft was operated at very low temperatures, some components proved troublesome. Aluminium electrolytic capacitors lost capacitance at temperatures of the order of -40°C (-40°F) and quartz

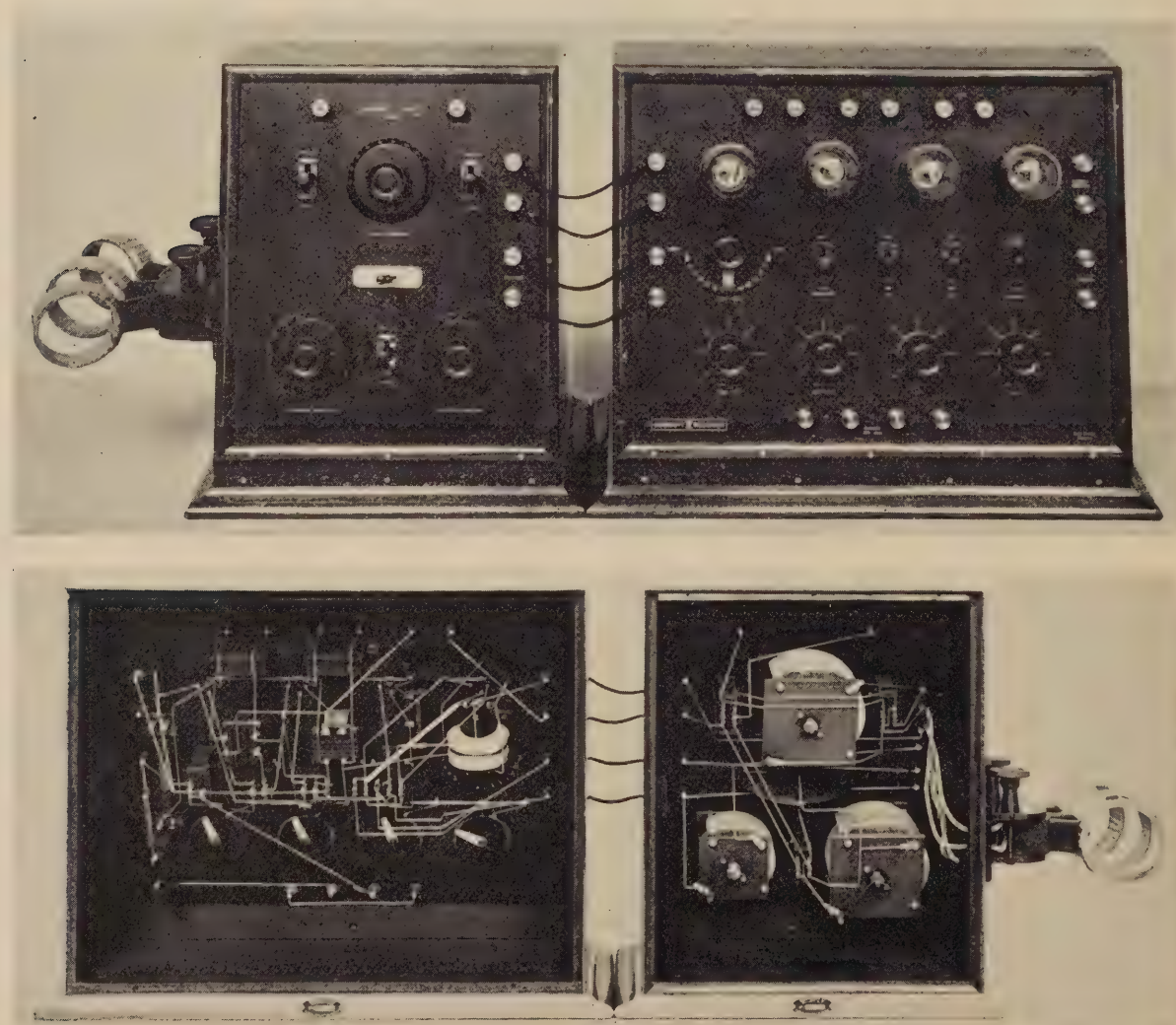


Fig. 2. Four-tube receiver built in 1923 showing front and rear views of tuner and detector-amplifier units. (Courtesy Science Museum, London, and Burndept. Ltd.)

crystals failed to oscillate, relay contacts 'stuck' and differential contraction caused many mechanical components to fail. It became necessary to develop improved components or to provide heat in some form to prevent failures of this type.

With the spread of the war to hot, dry climates such as North Africa, with high ambient temperatures, the continued trend towards miniaturization, and also the use of higher powers, problems of heat affecting the components became serious. The effects of heat were felt mainly in materials of which the components were constructed. Polythene coil formers melted and were replaced by formers of Mycalex (trade name) or ceramic. Metal and metal-oxide film resistors were used in place of carbon composition resistors in some cases and capacitors were developed with high temperature dielectrics such as PTFE. Materials such as ceramics, glass and mica were used whenever possible. Transformers used silicone-impregnated glass-covered winding wires and rotary switches used ceramic switch plates. All this work improved the performance of equipments under high temperature conditions of 150°C or so.

In the tropics, the effects of humidity on unprotected components was often disastrous. Failures occurred due to rusting and corrosion of metal parts, and to lowering of insulation resistance of insulating materials. Carbon composition resistors were liable to large variations in resistance value and wirewound precision resistors became open-circuited. Potentiometers with carbon tracks suffered from moisture penetration and all types suffered from corrosion problems of shafts etc., unless made of non-rusting material. Paper dielectric capacitors failed through ingress of moisture, causing a severe lowering of insulation resistance. Switches, plugs and sockets and valveholders also suffered from corrosion problems. Fungus growth in the hot damp conditions also caused loss of insulation resistance and a varnish spray technique was often used as a temporary palliative. Termites sometimes attacked communication wires and cables, making operating conditions even more difficult.

To solve these problems, two approaches were considered—first to hermetically-seal all components and second to hermetically-seal the complete equipment (a third solution for some ground equipments was to heat the components continuously to drive any moisture away). It was found that sealing all components proved difficult. Unless hermetically-sealed, moisture ions would penetrate the slightest pinhole or crack and even penetrate through plastics in time. Metal cases, with glass or ceramic end seals were developed for potentiometers with the elements fully sealed in metal cases. Oil-filled metal-cased and potted transformers were developed and also sealed relays.

Although these new components were now satisfactory, they were costly and where it was possible to seal equipments, this was done, often using the sealed components as a 'belt and braces' approach. When sealed equipments had to be opened in the tropics for servicing, moisture entered the equipment and nullified the sealing. Silica-gel crystals, which absorbed moisture, were often fitted in small containers in the equipment to take up this moisture.

No single environment is usually present by itself, but is a combination with others, e.g. humidity and high temperatures, high temperature and vibration, high altitude and vibration, mechanical shock in all climates, etc., etc. The testing of components under combined environments was necessary to reveal possible weaknesses. Vibration machines were mounted in high temperature and low temperature chambers and humidity temperature cycling was carried out. From all this testing the performance of components was gradually improved.

As in the case of Inter-Service standardization, co-ordination of the three Service requirements was done by the setting up of a Joint Services Radio Components Research and Development Committee (RC/RDC) formed in 1943. This committee stimulated and co-ordinated research and development of new components and materials. Government establishments and Industry, often financially sponsored by the RC/RDC developed new materials and components intended to satisfy the many conflicting requirements.

Waxed tubular paper-dielectric capacitors were replaced by metal-case tubular types with neoprene end seals. Metallized paper-dielectric capacitors were developed. Improved control of the temperature coefficient of ceramic-dielectric capacitors was introduced by manufacturers and new high-permittivity ceramic mixes developed. Glass-enclosed and sealed Grade 1 fixed resistors were developed but did not go into production. Many manufacturing improvements were introduced into Grade 2 resistor production and testing. Work on sealed variable resistors was sponsored by the RC/RDC and many types were made available. Transformers operating at higher temperatures, oil-filled and sealed in metal cans, were developed and also resin 'potted' transformers. Sealed relays and indicating meters were also designed and produced.

Following the war, the commercial success of component companies was concerned with the mass production of components for television receivers and radio sets. Service requirements dropped to a smaller proportion of the total components output but the lessons learned were valuable in improving the standard and reliability of commercial components.

It was this early post-war period which, in the opinion of the author, saw the beginning of the present American supremacy in technology. During the war many British and European scientists went to America to give details of their work so that production could commence in the USA free from bombing and war damage. Early radar experience, atomic energy, the magnetron, Gee navigation and many other technical developments were freely given to the USA. Later the Pacific war gave the USA experience in the value of electronics and built the foundations of a vast technology. In the UK and Europe a war-weariness prevented exploitation of electronic applications and it was probably not realised how important electronics was to become.

The author recently listed all major inventions in electronic components since the development of the Leyden jar capacitor in 1745 and it is significant that up to 1945 about 90% of all electronics inventions were from

Europe whereas since 1945 more than 90% of all electronics inventions are from the USA, due mainly to the American policy of 'buying brains' after the war.

In the UK, about 1948, the printed circuit was beginning to be used in conjunction with subminiature valves and many experimental circuits were made using both additive and subtractive techniques. In 1948, Bardeen, Brattain and Shockley of Bell Laboratories invented the transistor, and whilst the first point-contact devices did not raise a great deal of enthusiasm, the position was radically changed when the junction type of transistor was developed. In the early 1950s glass-dielectric capacitors, metal-film resistors, castellated metallized paper capacitors and subminiature relays were beginning to be used more widely.

About this time, subminiature components for use in transistor circuits were being developed. For the first time, h.t. voltages of 150 to 300 were not required and, therefore, components such as capacitors could be designed to withstand only 6 to 12V and (with the low currents at which transistors operated) resistors could be designed for very small power dissipation.

Also about this time, it was realized that the actual working volume of components such as resistors and capacitors was only a very small proportion of the total. In the case of a ceramic-dielectric capacitor fitted into a ceramic case only 1/225th of the actual working volume was effective whilst in a plastic-moulded carbon film resistor only 1/280th of the total volume was effective. Attempts to fabricate flat-film components led to the early thick-film and thin-film circuits now in use.

Also in the early 1950s, the concept of silicon integrated circuits was published by the author¹ and a model of a silicon 'solid circuit' was shown at an International Components Symposium in England in September, 1957. The first actual working model of an s.i.c. was made later in the USA by Texas Instruments and a patent was filed on 6th February, 1959 (Kilby). Again, the importance of this development was realized by very few people in the UK and the initiative passed to the USA to exploit the technique.

Other developments affecting components in the 1950s were automatic assembly techniques and 'potting' or encapsulation techniques. Machines for automatic insertion of tubular components into printed-wiring boards were developed. Axial lead tubular resistors and capacitors were loaded into special feed-containers and in the machine their leads were bent over, inserted through holes in the printed wiring board and dip-soldered. Unfortunately, the capacity of these machines was so high, e.g. up to 10,000 boards a day, that production quantities were rarely sufficient to make full use of them.

It may be worth a comment that not all American developments in this field were successful. The US Navy's sponsored work at the National Bureau of Standards on 'Tinkertoy' automatic assembly of ceramic plates carrying rationalized components was rarely, if ever, used and was reputed to have cost some 15 to 20 million dollars, whilst the US Army's 'Micromodule' programme costing several times this was overtaken by developments in integrated circuits, causing its eventual abandonment.

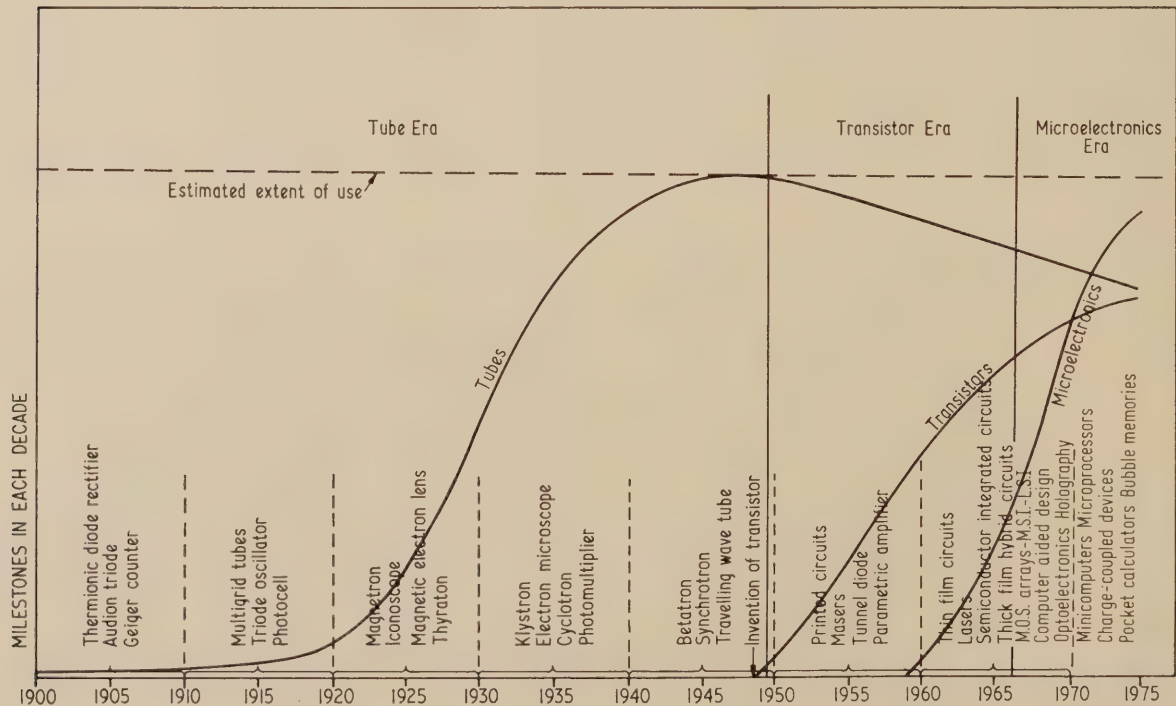


Fig. 3. The pace of electronics developments.

This period saw the exploitation of the junction transistor and its use with subminiature components on a printed-wiring board, with the connexions mostly made by dip-soldering. Extensions to the range of transistors and diodes, both in frequency, response and power output, were being rapidly made and transistorized equipment was being used for practically all electronic requirements by the mid 1960s.

During the early 1960s, the financial encouragement given by the American Air Force, Army and Navy to microelectronic manufacturers in the USA provided the necessary impetus to integrated circuit production techniques. The invention of the planar process made the process more viable and as experience was built up, more and more applications were found. Initially, digital circuits were developed for use in computers, this being the biggest market, but linear circuits were also being developed for general-purpose amplifiers etc. A typical integrated circuit of this period contained about 400 active devices on a silicon chip approximately one-tenth of an inch square. Fabrication processes for s.i.c.s were improved each year and, at the present time, circuit pattern delineation accuracies of the order of a few microns are being used in production. These improved accuracies were required for three reasons:

- (1) to raise the transistor frequency by closer spacing.
- (2) to fabricate more devices on a single slice to improve total yield.
- (3) to exploit metal oxide semiconductor transistor (m.o.s.t.) devices of a few microns size for large-scale integration.

The pace of electronics development is illustrated in Fig. 3 which shows the rapid rise of microelectronics and also shows milestones of major developments over the last seven and a half decades. It can be seen that more developments have taken place in the last decade than in all previous decades. Figure 3 also shows that there is little doubt that the exploitation of microelectronic techniques is essential to all current and future electronic systems.

The reliability of equipments is tremendously improved by redundant circuits, and integrated circuits lend themselves to this technique because of their small size and reasonable cost. The concept of 'total costing' of an equipment in which maintenance costs are included has now, after many years, become accepted.

Present work on computer aided design (c.a.d.) has shown the need for data banks on components. In c.a.d., accurate component equivalent circuits or modelling techniques are essential for computer circuit design, and these data are not always available even from the component manufacturer. Component data banks have, therefore, to be built up and many additional measurements made to provide the necessary modelling of transistors, diodes, resistors, capacitors, integrated circuits etc.

On many occasions over the past fifteen years I have said that the future of electronics lay in the full exploitation of microelectronics. This has now come to pass and the minicomputers, microprocessors, pocket calculators, etc., are with us. In the late 1960s, when stressing reliability with miniaturization, I produced a chart² of

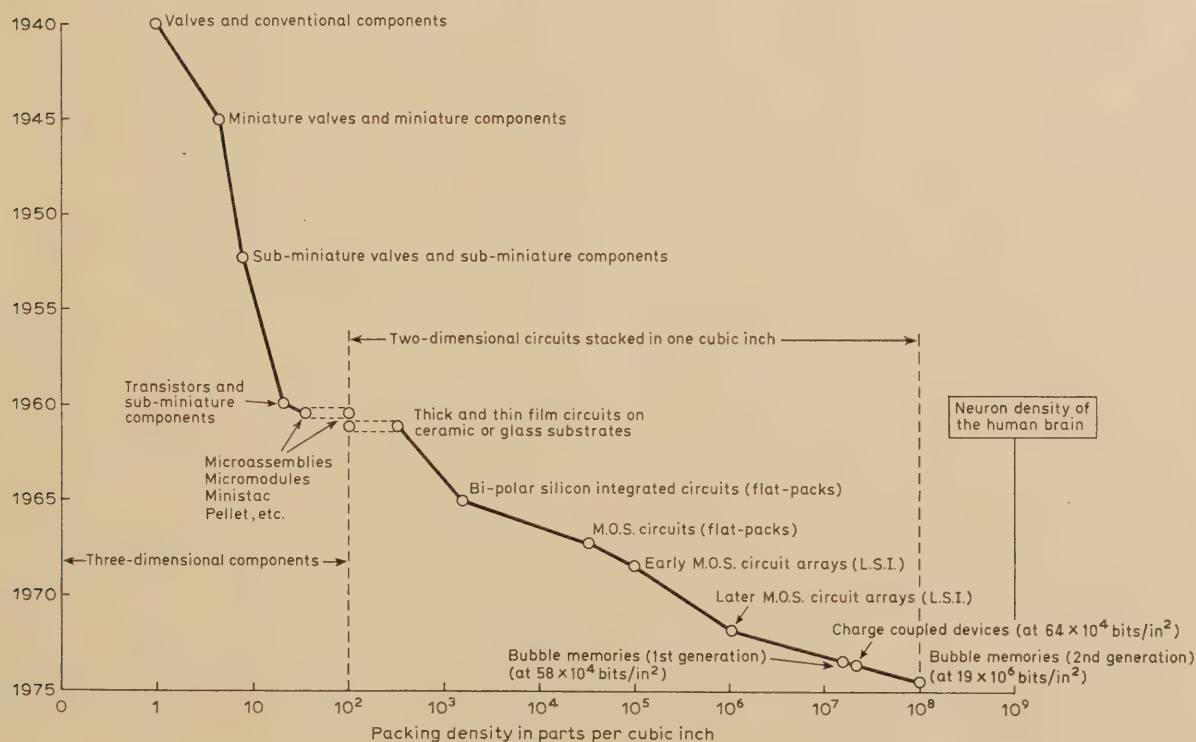


Fig. 4. Electronic miniaturization in terms of approximate packing densities.

packing densities achieved with components available from 1940 to that date. My early chart, although still in parts per cubic inch, has been brought up to date and is given in Fig. 4 which, in demonstrating the fantastic reductions in size, show that while once it was thought that it was impossible to match the packing density of the electronic components in the human brain, this position may no longer be regarded as the 'impossible dream'.

Component development in the 1970s must take into account new environments, such as space, with its requirement of high initial acceleration, long-term operation in a vacuum and with zero g. All communication and navigation satellites must have highly reliable components under these conditions as it is not yet possible to service them *in situ*. New components will also follow the development of holography and optoelectronics in addition to advances in microelectronics by further large-scale integration, integrated injection logic, charge coupled devices, bubble memories etc., all of which will generate entirely new component parts. Also in the 1970s the exploitation of electron beam fabrication techniques will produce ultra-miniature integrated circuit components.

The growth of the components industry has steadily increased over the past fifty years. From small beginnings in the early 1920s, there were approximately forty thousand people employed in about 150 factories in 1952. In this year, 1975, there are approximately 1200 component manufacturers, importers and distributors listed in the United Kingdom. In 1967, the total sales of components were £198M, comprising valves, tubes etc.—£48M; semiconductors—£33M, and passive components—£117M.

In 1975, the total factory sales are estimated to be around £440M, comprising passive components—£225M; semiconductors—£62M; integrated circuits, including hybrids—£45M; valves, c.r.t.s for television, etc.—£108M.

These figures are only approximate and subject to many interpretations but they suffice to show that the component industry is now one of the major commercial activities in the United Kingdom, and the importance of its future, particularly in integrated circuits, cannot be over-emphasized.

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Lasers and Optical Electronics

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Quantum electronics led to the development of stimulated emission devices, first the maser and then the laser. The latter has made possible many applications in optical electronics, the most important of which are in communication using optical fibres.

Introduction

The trend in electronics has always been to shorter time scales and higher frequencies, for the simple reason that only by such means can the rate of handling and transmission of information be increased. Lurking behind this argument, of course, is the none-too-subtle and dominating influence of economics, because by-and-large it is usually cheaper to produce a new system of higher capacity than to duplicate existing ones. If this were not so then there would be no point in employing frequencies higher than, say, 1 MHz since one might make a 100 MHz link by using a hundred 1 MHz systems in parallel. This is obviously not an economically practicable solution!

In the early days of electronics, operating frequencies of triodes and pentodes were gradually pushed up into the megahertz region until the effects of electron transit time and stray capacitance became dominant. Then came a period of technological trickery and ingenuity as devices were pushed to their limits, culminating in the development of coaxial triodes with grid/cathode spacings of 10 to 20 μm but it was obvious that a radically new technique was required before any further large advance could be achieved. This came about, as it were, by the acceptance of the adage 'If you can't beat

'em, join 'em', and instead of allowing the finite transit time to remain a limitation it was put to use, firstly in the klystron, in order to produce bunching and thus amplification. Klystrons are nonetheless limited by the transit time through the resonator gap and thus the true distributed interaction device, the travelling-wave tube (and the associated backward-wave oscillator), were later invented and are still widely used in microwave and satellite communications. However, even these are limited, by the difficulty in fabricating the associated slow-wave structure, to frequencies in the region of 10 GHz although some superb precision engineering produced the carcinotron operating at nearly 1000 GHz.

Developments in solid-state devices followed a similar path with the limitations of transit time and capacitance in transistors eventually being circumvented in transferred-electron devices such as Gunn diodes and the like, which in turn are limited by fabrication difficulties.

Quantum Electronics

Another 'breakthrough' was therefore required and came about via quantum electronic devices, firstly the maser[†] and then the laser. Since they do not depend on an associated structure (other than the mirrors) lasers are true distributed-interaction devices. Again their development followed a classic pattern in that the basic theory was enunciated by Einstein¹ in 1917, then largely ignored, and it was not until 1954 that the first successful device was operated. Interestingly enough this time delay is even longer than that between the prediction of electromagnetic waves by Maxwell in 1864 and their first demonstration by Hertz 23 years later.

The history of quantum electronics throws a very interesting light (if the pun may be excused) on the interplay between electronics and physics and on how pure and applied science are inextricably intertwined so that they complement and depend one upon the other. During the 1939-45 war scientists from many different disciplines were recruited to help in the development of radar and, as a result, became expert in electronic and microwave techniques. After the war they applied their new-found expertise to their own fields, notably in

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He is a member of the Optics and Infra-Red Committee of the Electronics Research Council and of the Technology Sub-Committee of the UGC.

Actively involved in Institution affairs for many years, Professor Gambling has served as Chairman of the Southern Section Committee, on the Education Committee and as an Ordinary Member of the Council; he was a Vice-President from 1970-1973 and from 1974.

Professor Gambling has contributed numerous original papers and reviews to the technical literature on a wide range of subjects, his main research interests being in microwaves, lasers, and more recently optical-fibre communications.

[†] The device is so named from its description *Microwave Amplification by the Stimulated Emission of Radiation* (not, as was sometimes unkindly claimed at the time, *Means of Acquiring Support for Expensive Research*). In laser the initial letter stands for *Light*.

microwave spectroscopy, giving rise to such distinguished research schools as that at Oxford. This powerful and novel method of investigation led to an explosion of knowledge relating to atomic and molecular structure so that technology's debt to science was amply repaid. The story does not end there as an extension of microwave spectroscopy produced the maser which engineers developed into a new and better frequency standard and into the most sensitive amplifier ever made, leading in turn to the first satellite communication system. Maser amplifiers also increased the sensitivity of radio telescopes and led to new fundamental knowledge about the stars. A similar interplay between technology and science has occurred with the laser.

Stimulated Emission

As mentioned above, the basic theory of stimulated emission, on which laser action depends, was first enunciated by Einstein by some brilliant deductive reasoning, and is disarmingly simple. Many types of atom and molecule can exchange energy with an electromagnetic field and since atoms can have only certain discrete values of internal energy, and the electromagnetic field is quantized, the frequency f which the radiation must have in order that interaction occurs is related to the change in energy ΔE in a very simple way, namely

$$\Delta E = hf$$

where h is Planck's constant.

There are three types of interaction process and the simplest of these to understand is absorption. If radiation of frequency f_{12} passes through an assembly of atoms having an energy E_1 and capable of absorbing energy so that their internal energy rises to E_2 , where

$$E_2 - E_1 = hf_{12} \quad (1)$$

then the number of photons absorbed per second is simply proportional to the density of the radiation u (i.e. to the number of photons) and to the number N_1 of atoms present in energy state E_1 , thus

$$\frac{dN_1}{dt} = -B_{12}uN_1 \quad (2)$$

where B_{12} is a constant.

A second process is that of spontaneous emission which, like radioactive decay, is a random process. In this case if the number of atoms present having an energy E_2 is N_2 then photons of energy hf_{12} are emitted even in the absence of an external source of radiation and the rate of emission is proportional to N_2 so that

$$\frac{dN_1}{dt} = AN_2 \quad (3)$$

These two processes are well known and are easily understood but Einstein's contribution was to show, from thermodynamic considerations, that there is a third process involving an inverse mechanism to absorption of radiation. Thus atoms of energy E_2 can be stimulated to emit photons by other photons of energy hf_{12} and the emission rate, as in absorption, is proportional to the number of stimulating photons (i.e. radiation density u) and to the number N_2 of atoms capable of

emitting, whence

$$\frac{dN_1}{dt} = B_{21}uN_2 \quad (4)$$

Hence in an assembly where all three processes occur and containing N_1 atoms having energy E_1 and N_2 with energy E_2 , then the net emission rate of photons is given by

$$\frac{dN_1}{dt} = Bu(N_2 - N_1) + AN_2 \quad (5)$$

since it turns out that $B_{12} = B_{21}$.

The first term in (5) represents amplification, if $N_2 > N_1$, because the stimulated emission is coherent, and in phase, with the stimulating emission. On the other hand, the spontaneous emission term represents noise due to the random nature of the process.

In the blinding light of hindsight it seems incredible that there was such a long time-lapse between the development of Einstein's theory and its practical demonstration. Indeed some electrical discharges in gases can produce stimulated emission so easily that it would not be surprising for it to have been observed accidentally very much earlier. One wonders whether the effect manifested itself in an experiment only to be dismissed as an anomalous result. This brings to mind the (apocryphal?) story concerning the discovery of X-rays by Roentgen who observed that photographic plates stored near a high-voltage cathode-ray machine were blackened and his curiosity was aroused. It is also said that at about the same time a technician who informed the Professor of Experimental Philosophy at the University of Oxford that photographic plates stored near his cathode-ray machine were blackened, was told to store them somewhere else. A sensible reply perhaps but not an inquisitive one.

The great difficulty in achieving amplifying conditions is, of course, that of achieving at least a quasi-stable condition in any system with $N_2 > N_1$ because, in thermal equilibrium, N_1 always exceeds N_2 as required by the Boltzmann relation:

$$\frac{N_2}{N_1} = \exp\left(-\frac{hf_{12}}{kT}\right) \quad (6)$$

The first clear recognition of the possibility of amplification of electromagnetic radiation by stimulated emission seems to have been by a Russian, Fabrikant,² who filed a patent in 1951 (although it was not published until 1959) and who had discussed various aspects in his thesis of 1940. However, his attempts to produce optical amplification in caesium were unsuccessful.

The first statement in the open literature about amplification was by Weber³ in 1953, followed by the detailed proposals of Basov and Prokhorov⁴ for a beam-type maser in 1954. However, the real excitement was caused by the short article of Gordon, Zeiger and Townes,⁵ in the same year, announcing the operation of the first maser using ammonia. Townes had conceived the required experimental arrangement three years earlier, based on his experience in microwave spectroscopy. In the years immediately following many other techniques were studied, but the only one to give any

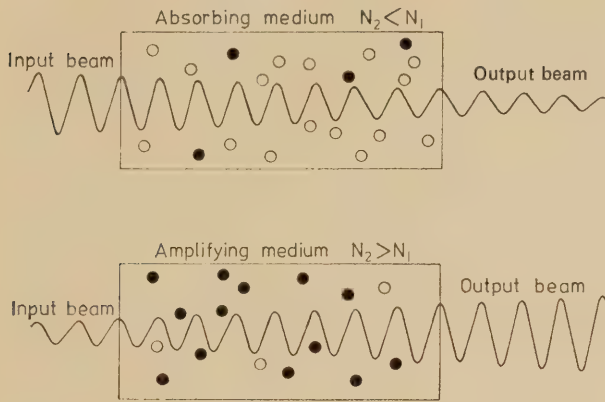


Fig. 1. Interaction of radiation with an atomic system. In the upper diagram energy is absorbed from the input beam because of the preponderance of atoms in the lower energy state (\circ). The lower diagram indicates the situation where there are more atoms capable of stimulated emission (\bullet) than there are of absorbing radiation with the result that the input beam is amplified.

degree of practical success was the three-level maser of Bloembergen⁶ which resulted in the ruby maser amplifier. The ammonia maser, now almost forgotten, proved to be a microwave oscillator (23.9 GHz) of very high stability, although the hydrogen maser is now preferred. It has only once been used as an amplifier, by Wilmschurst and Gambling,⁷ because of its very narrow bandwidth (~ 300 Hz) and low saturation power (10^{-12} W).

The Laser

Because of the great interest aroused by masers it was not until 1957 that further serious attention was given to the idea of producing an optical version of the maser.

In their classic article of 1958 on the principles of laser action Shawlow and Townes⁸ suggested potassium vapour as a possible medium and much effort was devoted to it but with no success. The reasons for this failure were rather puzzling, especially as other workers later found caesium vapour to behave as predicted. Another medium under consideration was ruby (Cr^{3+} in Al_2O_3) although an internal report at Bell Telephone Laboratories concluded that the existing material was much too poor to give any hope of success and the experts of the time expected that the first laser would be based on a gas. Great was the surprise and general jubilation therefore when Maiman, who had persevered with ruby, achieved laser action in 1960. Maiman's own jubilation was short-lived as the manuscript which he prepared announcing his remarkable result was rejected by *Physical Review Letters* and an historic scoop of scientific journalism was achieved by the journals *Nature* and *British Communications and Electronics* which carried the first announcement⁹ in the established scientific literature.

Some months later the helium/neon laser was successfully operated and there followed over the next few years a tremendous explosion of publications on laser transitions in hundreds of different materials and on the properties of laser devices. The author well remembers

the 3rd International Quantum Electronics Conference in Paris where, for a week, there were parallel sessions each day lasting from 0900 hours to nearly 1900, with more than 200 presentations and 1,100 participants. The pace of development was so rapid that two consecutive papers on gas lasers from the same organization were presented with the respective groups of authors not knowing the results of the others until they were read out. Those were heady days and one wonders whether we shall ever again see so much fundamental research done on such a fruitful topic.

Many thousands of papers and lasing transitions have appeared since 1960 and in addition to gas and solid-state lasers we have liquid, dye and semiconductor devices operating at fixed wavelengths from the sub-millimetre to the ultraviolet regions of the spectrum. The number of wavelengths at which laser operation has been achieved runs into many thousands, but only a relatively small number of lasers are manufactured on any scale. Applications are, to some extent, limited by the comparatively few wavelengths easily available, and the thought of having to develop a tailor-made device is a large deterrent so that the appearance of a number of tunable laser sources is of considerable significance.

Properties of Laser Radiation

The laser is essentially an electronic oscillator of extremely high frequency. Structurally it differs from most lower-frequency oscillators in its highly-multimode resonator, so that although it is possible to obtain, relatively easily, a Gaussian beam it is normally composed of a number of frequency components. For most applications this is no problem and if necessary a single axial mode can be selected by means of a resonant reflector.

The difference between laser, or coherent, radiation and incoherent light such as that emitted from ordinary light sources is similar to the difference between a sinusoidal signal and electrical noise. Electronic techniques would be in a very primitive state if the only sources available were noise generators and yet this was the case in optical electronics until the laser appeared.

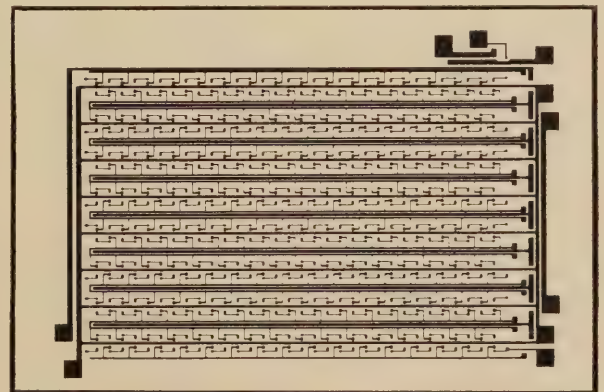


Fig. 2. Microelectronic circuit mask for a molybdenum-gate auto-registered m.o.s. shift register produced by laser machining. (By courtesy of Professor K. G. Nichols, Department of Electronics, University of Southampton.)

Before anything like the same development can take place at optical frequencies, as we take for granted in conventional electronics, we must learn to use the new devices and to produce the required optical components and systems. Significant progress is now being made in this direction.

The properties of laser light which make it potentially so useful are simple and obvious. For example, it can be collimated to a degree limited only by diffraction, whereby the half-angle spread θ of a beam produced by an aperture D is related to the wavelength λ by $\theta \approx \lambda/D$. Thus a helium/neon laser giving a beam of diameter 2 mm, for which $\theta \sim 0.3$ mrad, forms a cheap and simple light pencil which has found a score of uses in many diverse fields. A list of laser applications would be quite out of place here but one can perhaps mention a few. Simple lasers are now standard equipment on tunnel-boring machines which can be programmed to keep themselves aligned on the beam thus obviating the tedious and time-consuming surveying techniques. A more homely application is reflected in a ten-million-dollar order recently received by the Spectra Physics Corporation in the USA for laser scanning equipment to be used at supermarket cash desks. The checker simply moves the items, which are suitably marked, across the beams in a simple, fast, natural motion. The scanning equipment then records the price, operates the till, alters the store inventory and provides an itemized tape for the customer.

In addition to collimation a coherent beam can be focused by a lens of focal length f to a spot of diameter $d \approx f\lambda/D$. Thus if $f \approx D$ then $d \approx \lambda$ and power den-

sities can be achieved which are capable of melting and vaporizing any known material. Obviously in most cases mechanical drilling is still the simplest and cheapest method but with refractory, brittle, poisonous or high-purity materials, or where precision and minimum effect on surrounding areas are important, laser machining comes into its own. In fact one of the first applications of lasers was to the drilling of diamond dies for wire drawing, resulting in a reduction of the time involved in each operation from 12 h to 20 min. With the greatly increased complexity of microcircuits requiring greater intricacy and closer tolerances, the speed, accuracy ($\sim 1 \mu\text{m}$) and flexibility of laser machining is being more widely appreciated. Thus complex masks that take 4 days to make by conventional techniques can be cut in 10 min. Computer control can easily be incorporated so that changes can be made rapidly and frequently.

Optical-fibre Communications

Perhaps, at long last, the greatest impact of optical electronics will be in the field of communications. From the very beginning in 1960 one of the most exciting possibilities was that of exploiting the potentially enormous bandwidth capability of lasers as carrier-frequency sources. The difficulties are well known. Propagation through the atmosphere is limited to distances of a few kilometres because of atmospheric turbulence, even in fine weather. Outer space is an ideal medium but the number of applications outside the Earth's atmosphere is always likely to be small. Techniques have been devised, with great ingenuity, for protecting laser beams from the vagaries of the atmosphere by enclosing them

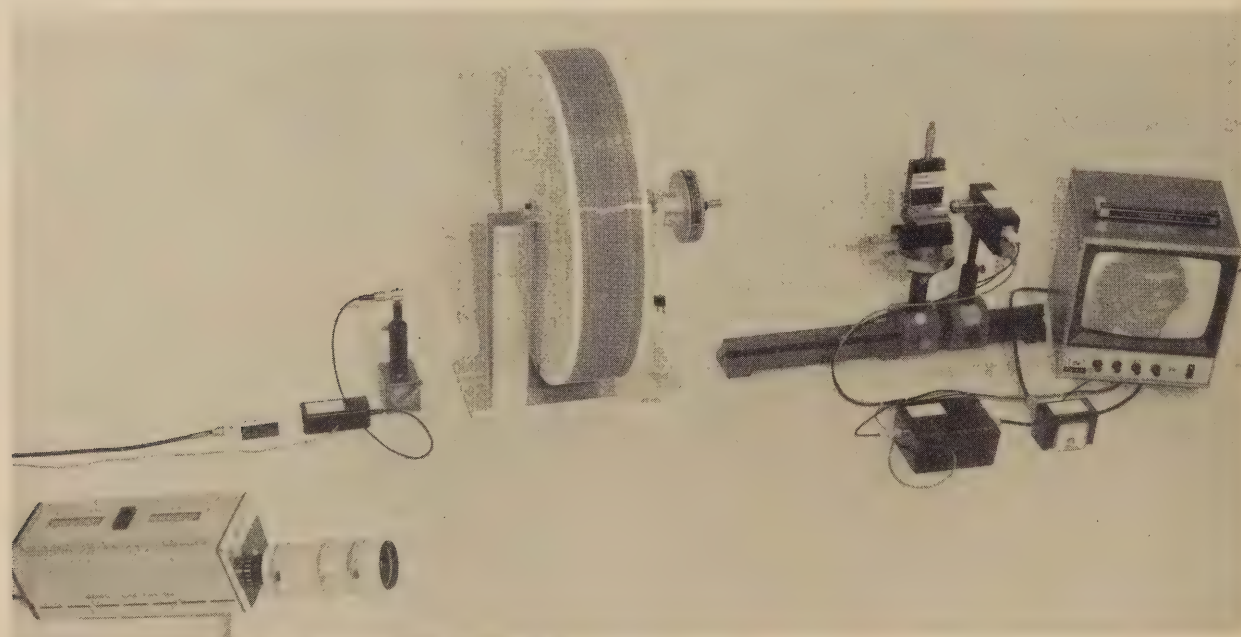


Fig. 3. Glass fibres will play an important part in long-distance communications systems of the future. The photograph shows the transmission of television pictures along a 1 km length of such fibre. Both the fibre and the link have been made in the Department of Electronics at the University of Southampton. This

equipment was used for the first commercial application of fibres to television broadcasting when an entire colour television programme, from the Royal Institution, was passed through it en route to the transmitter.

in pipes and correcting for the effect of spreading due to diffraction.¹⁰ Technically this can be done and transmission losses as low as 1 dB/km have been achieved but the cost is considerable and quite uneconomic at the present time.

Another method of providing guidance, and of cunningly circumventing the problem of light travelling in straight lines, is to use a fibre consisting of a glass core having a high refractive index surrounded by a cladding of lower index. As early as August 1964, in an address to the British Association for the Advancement of Science, the author¹¹ speculated on the use of light and glass fibres in the telephone network, instead of electric currents and wires, but developments did not start in earnest until publication of the classic article of Kao and Hockham¹² of STL in 1966. At the time the problem seemed a formidable one; the attenuation of existing fibres was about 1000 dB/km, the bandwidth was expected to be low and fibre bundles were fragile. Since then enormous strides have been made resulting in fibre attenuations¹³ of 2 dB/km produced as a matter of routine, bandwidths of 1 GHz in a 1 km length¹⁴ of fibre having a diameter of 100 μm , and fibres coated with nylon which are too strong to be broken by hand. Such fibres are flexible and capable of being incorporated into simple but effective forms of cable. The bandwidth of a single fibre is much greater, and the attenuation lower, than existing copper coaxial cables and the diameter is considerably smaller. Thus the capacity of the present telephone network could be very greatly increased, with little additional installation expense, by the gradual introduction of optical fibre cables.

Trial installation cables of optical fibres have been laid in a number of countries and have given satisfactory and reliable service. Techniques for making joints and junctions are being rapidly developed while a fibre cable of, say, 1 cm diameter is more easily laid than a much

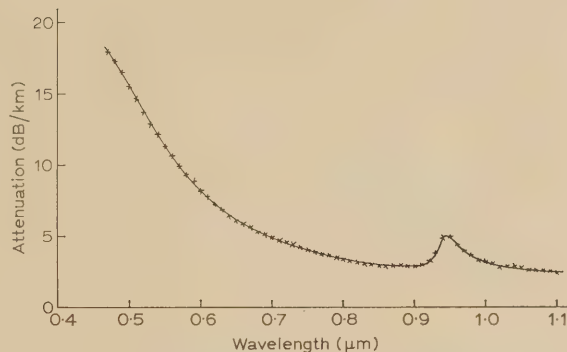


Fig. 5. Spectral attenuation curve of a 1.2 km length of phosphosilicate optical fibre.

heavier 10 cm diameter copper coaxial cable. An optical fibre system will be simple in concept, with electrical signals turned into optical ones at the input and a reverse process at the output. Satisfactory detectors already exist but the lifetimes of present-day semiconductor lasers need a significant improvement. On the other hand, it has been shown¹⁵ that light-emitting diodes, which already exist with long lifetimes, could well be adapted to give the same bandwidth. Optical fibres will probably find their first application in special-purpose links but might be put into developmental trials for short links between local exchanges within five years.

Conclusions

The trend to higher frequencies received a tremendous impetus with the advent of the laser. However, technology can normally only cope with gradual improvements in techniques and cannot implement easily, or quickly, an advance in frequency capability of four or five orders of magnitude. Furthermore, the laser has to await the development of associated techniques before it can be properly used. For example, even if the cavity magnetron had been invented in 1938 radar as we know it would not have appeared overnight; it would still have been necessary to await the development of waveguide components, T-R cells, aerials, circulators, isolators and so on before the new device could be used properly in an effective system. In the same way, lasers cannot be fully exploited in isolation and are dependent on the creation of many other associated techniques and components. In fact it is necessary to think in terms of laser systems and the increasing number of applications in all fields is due, in part, to an appreciation of this factor.

The past fifteen years have shown tremendous promise and have provided exciting new experiments as well as some disappointments. Nevertheless, steady progress in optical techniques is being made and I am sure we shall look back on this period as the formative one for optical electronics.

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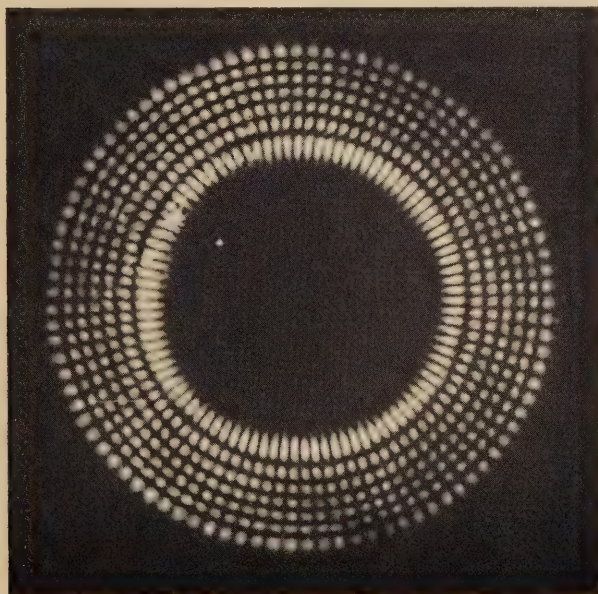


Fig. 4. High-order mode pattern of a multimode optical fibre. (By courtesy of Mr. W. J. Stewart, The Plessey Co. Ltd., Towcester.)

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Fixed Communications

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The growing demand for increased world-wide communications has stimulated and been stimulated by technological developments. The past, present and future interrelations of cables, h.f. radio, communications satellites and tropospheric scatter systems are surveyed.

In the world today there is an ever-increasing requirement for stable and reliable communications. Indeed, it is a feature of modern civilization that people should be able to speak to people over short or great distances, machine to machine telegraphically, computer to computer by the transmission of data, etc., and it is through networks of fixed communications that these services are provided.

Fixed communications may broadly be divided into two categories, those used on overland routes in which a series of short distance links is possible with readily accessible relay points, and those used over long distances such as across oceans or deserts where there is virtually no *en-route* accessibility. Although the basic principles underlying the design in these two categories are similar, there are differences in the practical application and, as might be expected, the development of short-haul readily accessible systems tends to lead that of the long-haul systems.

From the engineer's viewpoint the transmission of all types of information, no matter what form or how it is packaged requires the availability of sufficient bandwidth over the communications medium to cope with the desired volume and rate of information flow. Thus in considering different communications systems it is useful to compare the bandwidth transmission capabilities, and one may conveniently take a telephone channel which requires a bandwidth of 4 kHz as a basic unit.

The growth in demand for communications is stimulated by advances in technology leading to systems of greater reliability and capability, coupled with a ready appreciation of the uses to which these advances can be put. A typical example is seen in the field of international telecommunications where advances made

during the past two decades—which will be discussed later—led to the release of a suppressed demand which could not previously be satisfied and indeed stimulated that demand. Since that time the volume of international telephone traffic has continued to increase roughly at the rate of 20% per annum and of telex by a similar percentage. It is true that this demand is affected by World Trade cycles but such fluctuations have hitherto been largely smoothed out by the increasing familiarity of the use of these services as they become part of everyday life. As an example of network growth, the Commonwealth Caribbean network comprised 650 voice channels in 1966, 3000 in 1974 and will have a capability of some 10 000 channels in 1982.

One of the two principal methods of providing broadband communications on overland routes up to a few hundred miles is by the use of pairs of coaxial tubes, one pair in the 'go' direction and one in the 'return'. To facilitate interconnection across national frontiers some standardization of physical and electrical characteristics is required and, under the auspices of the International Telecommunications Union, there are two recommended sizes of tubes which are commonly used having diameters of 9.5 mm and 4.4 mm. Typically a bandwidth of 12 MHz may be transmitted over 4.4 mm coaxial tubes giving some 2700 voice circuits and such systems would require repeaters (amplifiers) every 2 km (1.25 miles). If the system is designed for a lesser number of voice circuits, e.g. 960, then greater spacing between repeaters is permissible—in this case 4 km. The d.c. power for the repeaters is provided from one or both of the terminal stations using the inner tubes of the 'go' and 'return' pairs. The latest development in this country has been carried out by the British Post Office in cooperation with British Industry. This is the 60 MHz f.d.m. system which uses the 9.5 mm tube with repeater spacing of 0.97 miles yielding no less than 10 800 voice circuits. The first of such systems is now being installed comprising 18 tubes layed up together giving nearly 100 000 voice circuits.¹

The other method widely used today for broadband transmission is by radio relay of microwaves mainly in the 2, 4 and 6 GHz bands. At these frequencies propagation is virtually limited to the direct visual range and therefore typical distances for one hop would be of the order of 30 miles depending on the height available at each end and the intervening topography. However, highly directional aerials having gains of 40–50 dB can be designed which are still relatively

Mr. A. S. Pudner (Fellow 1961, Member 1943) was with Cable & Wireless Ltd. from 1934 until he retired in 1974 as Engineer-in-Chief and a member of the Court of Directors. Mr. Pudner served at many overseas stations as well as on cable ships. During the Korean War he was Manager of the Cable & Wireless field telegraph unit and he was appointed M.B.E. in December 1952 for his services to the unit. He represented the Company at international conferences on numerous occasions.

Mr. Pudner served on the IERE Membership Committee from 1963 to 1965 and since 1969 he has been a member of the Finance Committee. He was elected to Council in 1968 and was a Vice-President from 1969 to 1972.

compact and with such aerial gain the power output from the microwave transmitter is seldom more than a few watts. Although propagation conditions broadly can be regarded as quasi-optical, nevertheless the medium is still subject to some variations due to temperature gradients near to the ground which result in changes in refractive index and fading due to multi-path transmission. However, these effects can usually be mitigated and an acceptable performance maintained by employing diversity transmission either from two spaced aeriels at each end or by the use of two frequencies with signal combiners at the receivers. Microwave systems are suitable for carrying all forms of information, one r.f. channel being capable of transmitting 2700 voice circuits or one television channel, and the technology is so well developed that these systems employing large numbers of relay stations are used to provide main trunk routes across continents.

In highly industrialized countries, such as the UK, the existing 2, 4 and 6 GHz bands are becoming severely congested and therefore the quest for higher frequencies continues. But propagation above 10 GHz brings further problems since it is the more prone to atmospheric absorption due to rain and general weather conditions resulting in a rapid increase in path attenuation of a variable nature. For many years the relationship between attenuation and rainfall, size of raindrops, etc., has been studied by scientists. It is to these problems

that engineers are now addressing themselves and the lines of approach have generally been directed towards the statistical analysis of rainfall in different areas, diversity of routing, the optimum separation of such routes and the shortening of individual path lengths.

Future demands for overland fixed communications are expected to grow exponentially to the end of the century and beyond, in spite of current economic conditions, not only as a result of normal expansion of telephone, telex and existing data services but also as a result of demands for more sophisticated services requiring considerably greater bandwidth. Examples of these services are video-telephones which will need one hundred times the bandwidth of a normal voice circuit, visual access to computers, closed-circuit television and similar visual systems. This means that there will be a requirement for systems capable of transmitting bandwidths of an order or more than that at present available. Apart from continued development of existing systems, one of the methods by which this aim can be achieved is by transmission over waveguides on millimetric wavelengths. Waveguides have, of course, been used for many years in microwave radio equipment and their development for trunk networks is now well advanced in a number of countries. The work on these systems is generally based on the use of a 5 cm diameter dielectric or helix type circular guide operating in the band 30–100 GHz. Within this band losses as low as

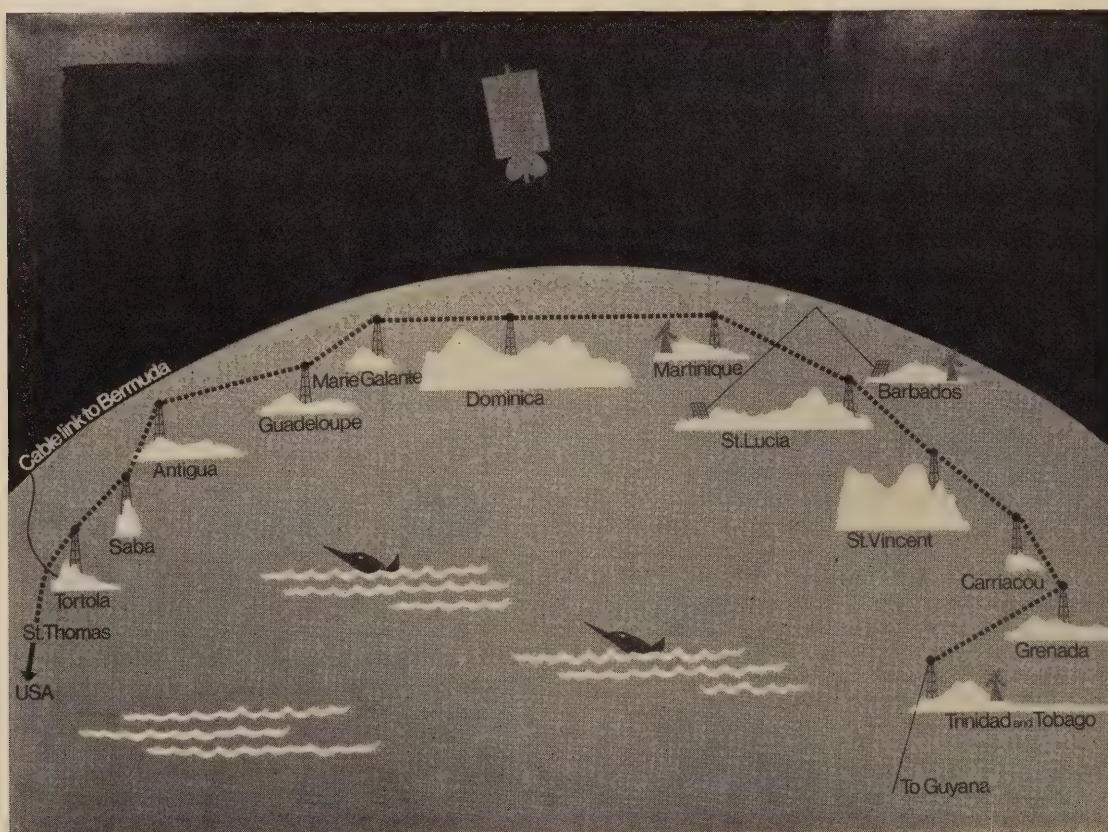


Fig. 1. The Caribbean microwave system, the longest island-hopping link in the world, extending over 800 miles from the Virgin Islands in the north to Trinidad in the south. (*Cable & Wireless diagram*).



Fig. 2. Transoceanic cables in 1974, showing the numbers of channels in use. (*Cable & Wireless diagram*).

2–3 dB have been achieved per mile run. Repeater spacing will depend not only on the basic waveguide loss per mile but also upon the horizontal and vertical bends along the route which result in further attenuation. Thus, in planning routes for waveguide systems there are the same problems as with railways and motorways, and repeater spacing of the order of 10–20 miles will probably be required. Although these systems may confidently be expected to reach the stage of commercial production by the end of this decade, their actual use for fixed communication will depend largely on economics. At the present time production of waveguides is a matter of precision engineering and therefore the initial capital cost is high compared with other systems, but they will be capable of transmitting 200 000 or more voice circuits and will thus be eminently suitable for the densest trunk routes.²

Finally in this category of short-haul fixed communication systems, mention must be made of the use of laser beams with optical fibres as the transmission medium. Such systems are still in the early stages of development and will probably follow on somewhat later than millimetric waveguides. This subject is dealt with in another paper† but suffice it to say here that these systems show great potential for broadband communication and could well prove economic as feeders into a waveguide trunk network.^{3,4}

Turning now to the second category of fixed communications, the long-haul routes across oceans, etc., which cannot conveniently be served by the extension of overland methods, the doyen of such systems must surely be the submarine telegraph cable. The first of these cables was laid across the Atlantic in 1866 and by the end of the century a worldwide network existed. However, their information-carrying capacity was small—equivalent to about two teleprinters at each end—and it was thus basically economic reasons which led to the

abandonment of these systems after almost one hundred years of service.⁵

In the mid-1930s h.f. radio in the band of roughly 3–30 MHz emerged as a new form of fixed communication suitable for commercial operation, initially transmitting only the written word and later, at the end of World War II, also the spoken word. The unreliability of this form of communication in those early days is well known, but since that time scientists and engineers have made great progress in their knowledge of the ionosphere using such techniques as oblique incidence h.f. sounding from ground installations, top-side sounding from technology satellites, measurement of electron density in the layers and measurement of the vertical arrival of radio waves reflected or refracted from the ionosphere. The greater knowledge of the propagation medium resulting from this continuing research has enabled engineers to choose optimum operating frequencies, most suitable aerial directional properties and minimum radiated power, all of which are fundamental to the avoidance of interference in this congested band.⁶ There have also been continual developments and improvements in such things as modulation techniques, frequency stability, automatic tuning, etc., as a result of which the modern h.f. radio system will now provide four voice channels with a performance and reliability approaching that of the modern broadband systems for almost 90% of the time. This, coupled with the flexibility and low capital outlay has resulted in a continuing demand for these systems even in this age of satellites and coaxial cables, and it is difficult to visualize a time when this will not be the case.

Although h.f. radio continues to play a very important part in fixed communications, the band 3–30 MHz can only carry a small fraction of the total load today. There are two types of system which provide the bulk of the world's long-haul fixed communication and these

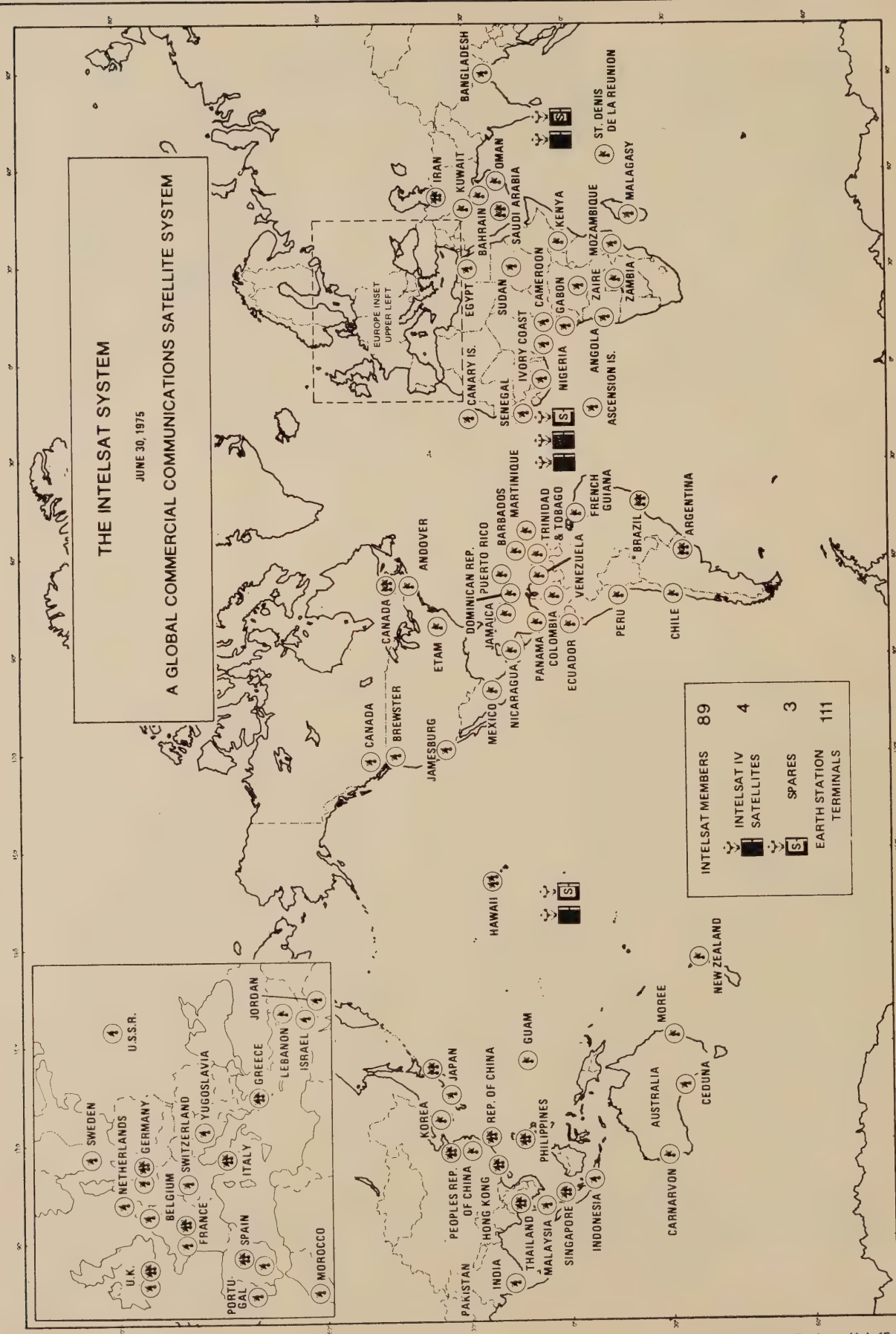


Fig. 3. The Intelsat system. (Communications Satellite Corporation diagram).

are submarine coaxial telephone cables and satellites. As will be seen later, both systems are capable of transmitting bandwidths of 30 MHz, equal to the total h.f. spectrum.

Before considering the present worldwide submarine coaxial cable network, it is perhaps of interest to review the growth in this technology since the first long-haul deep sea system was laid across the North Atlantic nearly twenty years ago. This system comprised two coaxial cables which transmitted East-to-West and West-to-East respectively and provided 36 4-kHz voice circuits. The bandwidth in each direction was 144 kHz and to overcome the loss of some 3200 dB at these frequencies submerged repeaters were required every 37 miles. The power to operate these repeaters was from a d.c. supply at the extremities of the cable using the central conductor and an earth return. So great was the success of this system that there was an immediate demand for an increase in the number of voice circuits. This was partially met by reducing the voice circuits from 4 kHz to 3 kHz bandwidth with negligible degradation in quality thus increasing the capacity to 48 voice circuits. Another device used was known as time assignment speech interpolation (t.a.s.i.). This was based on the premise that in any two-way conversation usually one person will be listening whilst the other is speaking. Thus by the use of voice-operated electronic switching circuits the idle 'listening' channel can be used by another speaker. By this means the capacity of the system was increased to 88 voice circuits.

Subsequent developments in cable design resulting in a reduction of attenuation by one-third, and in repeaters by incorporating directional filters, resulted in a British system which operated in both directions over a single cable and yielded 80 voice circuits (without t.a.s.i.). The total bandwidth for the two directions was 0.6 MHz and repeater spacing 26 miles. Further developments during the past decade, no doubt spurred on by potential competition from satellites, led by stages to the currently largest British system in operation which provides 1840 voice circuits using a bandwidth of 14 MHz and with repeater spacing down to 6.5 miles. The latest coaxial cable system to be fully developed in this country, the first of which will be laid next year, will have a bandwidth of 45 MHz yielding some 5500 voice circuits and will require repeaters approximately every 3 miles.⁷

It is interesting to note how the repeater spacing has come down from 37 miles in the case of the first transatlantic cable to 3 miles for the system described above, and to speculate on how much further it is feasible to go in reducing repeater spacing. These cable systems are designed to provide trouble-free service for 20–25 years and therefore the repeaters have to meet and maintain the most stringent performance objectives throughout this period. Clearly the more repeaters in the system the more stringent must be their individual reliability. As the purpose of the repeater is to compensate for cable attenuation, it would seem that development of lower loss cables could well provide the next breakthrough.

The alternative to submarine coaxial telephone cables

for broadband long-haul fixed communications is the communication satellite. This is in fact a particular type of microwave radio relay which works on the same line-of-sight basis but poses special problems owing to obvious limitations in primary power on board the satellite, its inaccessibility after launch, and the high path attenuation due to the excessive route distance. Owing to this high attenuation and the power limitations on the satellite, the most suitable frequency band is 1 GHz–10 GHz, being limited at the higher end by atmospheric absorption as with terrestrial microwave systems, and at the lower end by galactic noise.⁸

The first internationally owned satellite, *Intelsat I*, was put into operation in 1965. It was placed in a geostationary equatorial orbit, that is at an altitude of 22 400 miles, in a longitudinal position 30° West for transatlantic operation. It had a mass of 39 kg (85 lb), primary power 45 W from solar cells and was capable of relaying 120 voice circuits or one television channel. The *Intelsat I* system was to some extent experimental for two main reasons. Firstly, it was to ascertain whether reliable communication could be maintained in spite of the high path loss of 200 dB; however, the Earth stations employed the now well-known parabolic reflector type aerials—diameter 85–100 ft—with cryogenic-cooled low-noise amplifiers and in this respect it was a great success. Secondly, it was to determine whether the transmission delay, Earth–satellite–Earth, of 250 ms was operationally acceptable. The significance here was that a transmission delay beyond about 300 ms (the internationally agreed limit) could interfere on a subjective basis with the free flow of conversation between individuals on a telephone circuit. A major decision therefore had to be taken on the type of orbit for future systems. On the one hand, the geo-stationary orbit required only one aerial but had long transmission delay; whilst on the other, the lower level orbits would mean a succession of satellites moving around the Earth and therefore at least two aerials at each terminal for tracking purposes; there would also be Doppler effect to contend with, but the transmission delay would be reduced.⁹

The decision was taken to continue with satellites in the geo-stationary orbit and this is used for all internationally-owned satellites today. It is perhaps paradoxical that this decision ensured a future requirement for submarine coaxial cables. This arises from the fact that any particular satellite is only 'visible' across one-third of the Earth's surface and thus a telephone call between points which are not served by the same satellite must be completed by terrestrial links since a double satellite link would result in an unacceptably high transmission delay of over 500 ms. As a practical example consider the case of a station in the Arabian Gulf which works through the Indian Ocean satellite. As this satellite is not visible from North or South America, a telephone call from say Bahrain to USA would have to go by satellite to UK and from there onwards by coaxial cable which would add a mere 30 ms to the transmission delay in crossing the Atlantic. This time delay does not, of course, affect one-way transmission such as television or data for which satellites are eminently suitable.

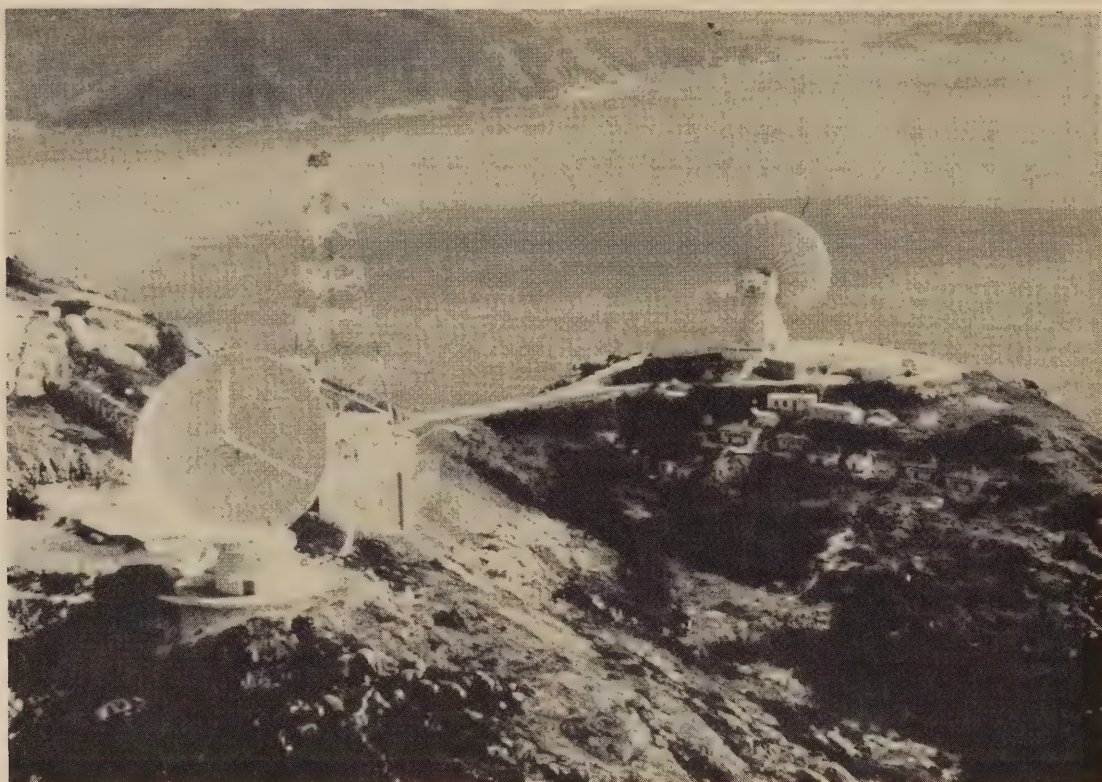


Fig. 4. The two satellite Earth stations at Stanley Peninsula, Hong Kong. (Cable & Wireless photograph).

Since the first communications satellite was flown in 1965, there have been rapid advances not only in the electronic packages but also in rocketry, telemetric control of satellites, etc.—no doubt, spin-off from the NASA space programmes. The fourth generation of communication satellites has been in operation since 1971. *Intelsat IV*'s have a mass of 690 kg (1500 lb), primary power of 569 W, twelve transponders and a maximum capacity of about 4000 voice circuits plus one television channel. These satellites are equipped with two pairs of aerials, one pair having spot beams (4.5° width) for the denser traffic routes and one pair for full coverage (17.3° width). Remote switching enables some commutation to be carried out as between aerials and transponders. Frequency division multiple access is employed so that any Earth station having a frequency allocation in the satellite can readily work with any other station using the same satellite and thus there is considerable flexibility.

Plans are now being drawn up for the next generation of satellites which are expected to be ready for operation towards the end of the decade. The intention is to use 14 GHz for transmission to the satellite and 11 GHz from satellite to Earth. These may well suffer increased attenuation due to atmospheric absorption and therefore some form of diversity operation may be necessary. It may be surprising that any sort of congestion should exist in the geostationary orbit particularly as Earth station aerials have a beamwidth of only about 10 minutes of arc and therefore the re-use of frequencies

is possible with satellites spaced as little as $2\frac{1}{2}^\circ$ apart. However, the longitudinal positioning of satellites is restricted by the operational coverage required. As an example, the Indian Ocean satellite is in a position 62.5° East of Greenwich as this will just permit communication between UK (Goonhilly) on the one hand and Japan/Australia on the other. Moreover, the internationally agreed frequencies for communication satellites is limited to two bands of only 500 MHz in the range 1–10 GHz and hence the need to explore higher frequencies.¹⁰

There is one further type of fixed communication suitable for transmitting a few hundred voice circuits over distances of 100–400 miles which depends upon the refraction and forward scattering of radio signals in the u.h.f. band by the troposphere. These tropospheric scatter systems are particularly useful for routes where the intervening terrain is inhospitable or too inaccessible for radio relays and where other long-haul systems such as coaxial cables or satellite communication cannot be justified. For example, within their range they are used for crossing deserts, swamps, short overseas routes to islands and between oil rigs and the mainland.

Due to the random nature of the propagation mechanism the energy refracted and scattered is small and the effective path loss is of the same order as an Earth-satellite route in addition to being subject to wide fluctuations, typically 40 dB in the short term. The path loss is dependent, *inter alia*, upon the scatter angle, that is the angle through which the radio waves

must be refracted, and therefore the height of the aerials at each end is an important factor in the system design. Typically transmitter powers are in the range 1–10 kW and high-gain antennas of the Cassegrain-fed parabolic reflector type having diameters 8–100 ft are used. In view of the high fading ratios experienced on these systems it is usual to have two antennas at each end so as to provide quadruple diversity reception.

Although tropospheric scatter systems are regarded by some as rather a 'brute force' method of communication, nevertheless they fill a useful gap between short-haul and long-haul systems and there are many in operation today.

In reviewing the various methods employed today for fixed communications it is interesting to note how 'guided' systems using coaxial cable, etc., and those relying on free space transmission have both been developed to more or less the same extent. Each of these two basic methods has its own advantages and disadvantages. The 'guided' systems for example utilize a transmission medium whose characteristics are virtually constant, and therefore performance objectives can be specified with confidence and achieved with considerable accuracy. Problems with noise are minimal and bands of frequencies may be re-used at will. Operationally there is some inflexibility since these systems cannot readily be extended in capacity beyond that for which they were designed, nor the chosen route changed.

What can be more fixed than a coaxial cable buried in ducts across the country or laid across the floor of the ocean?

Radio systems, on the other hand, utilize a variable transmission medium over which there is no control and are prone to interference from electrical noise, reflexions, etc., and also to problems of frequency congestion. Thus system objectives can only be specified, and performance subsequently measured on a statistical basis. However, with good system design adequate reliability is achieved and it has been seen that with the exception of troposcatter installations there is considerable flexibility. Undoubtedly there will continue to be circumstances which will favour the choice of one method rather than the other, but at all events the ever-growing demand for telecommunications should provide ample stimulus to the developers and manufacturers of communications equipment of all types.

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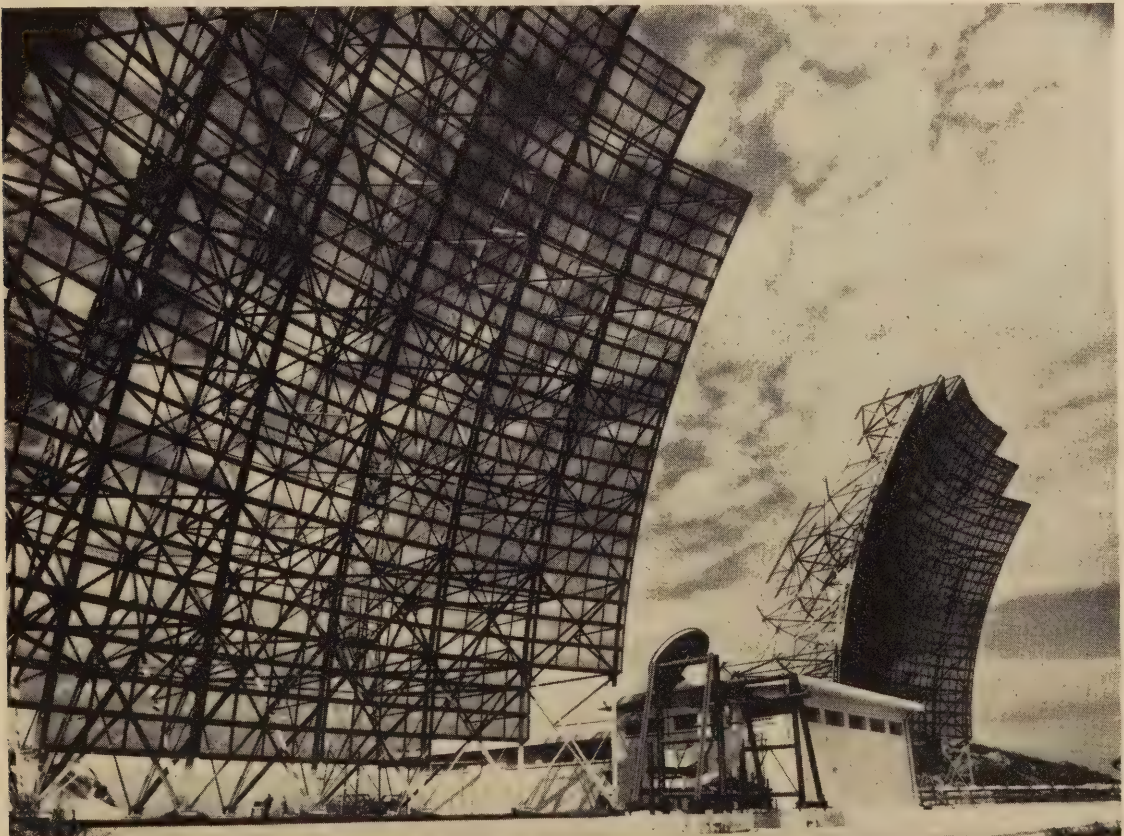


Fig. 5. Troposcatter station at Hong Kong, working to Taiwan (400 miles). (*Cable & Wireless photograph*).

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Fifty Years of Mobile Radio

J. R. BRINKLEY, C.Eng., F.I.E.R.E.

Marine mobile radio was a well established international service when the Institution was founded. Land mobile in contrast, was in its early conceptual stage. Pioneered just before and during the war, its large-scale development began in the 1950s. There are now 200,000 vehicles equipped in the UK alone but this represents less than 2% of all vehicles and great scope remains for further expansion and innovation.

Introduction

Mobile radio is used to-day on a scale and for a variety of applications which were quite undreamed of in 1925 when the Institution was born. Without it, modern shipping and airline services could not operate. In road and rail transport it is becoming indispensable. In the last decade it has opened up major new fields of application with the development of pocket radio-telephones and tiny radiopaging receivers with prodigious performance. It reached a peak of sophisticated achievement in 1969 when television pictures were transmitted to Earth by the American astronauts walking on the surface of the Moon.

In 1925 little of this was dreamed of and the early efforts of the pioneers of that time to make mobile and portable radio practical must have been treated with scepticism if not scorn. This was true of all mobile communication applications save one. In the marine field, radiocommunication had not only been demonstrated to be practical, it already had a history of twenty-five years of successful operation and was established as a vital requirement for safety of life at sea with mandatory government regulation to back it.

In order to recall something of the fascinating story of mobile radio during the life of the Institution one must go back to its beginning in the marine world twenty-five years before the Institution was born.¹

Mr. John R. Brinkley (Fellow 1952, Member 1948) is Chairman and Managing Director of Redifon Telecommunications Ltd., which he joined in 1971. He is on the Board of Rediffusion Ltd., and Chairman or Board Member of several other companies in the group. His career in telecommunications began with the British Post Office at Dollis Hill Research Station, and during the war he was seconded to the Home Office where he was responsible for the development of v.h.f. radio for the police, fire and civil defence services. In 1949 Mr. Brinkley joined Pye Telecommunications as Chief Engineer, becoming Technical Director and subsequently Managing Director. In 1967 he joined ITT as International Manager of Mobile Radio. He has been responsible for many innovations in the mobile radio field and played a leading role in the introduction of 12.5 kHz channelling in the v.h.f. bands in the UK.

Mr. Brinkley is a member of the Home Office Frequency Advisory and Mobile Radio Advisory Committees. He served as a member of the Institution's Council from 1963-1966.

Early History

The early futurologists who so imaginatively predicted space travel, aeroplanes and submarines seemed to have missed out entirely on radio communication and it must therefore have been to an astonished world that Marconi first demonstrated shore to ship communication. The date was May 1897, the ship was the S.S. *Mayflower* lying off the Isle of Wight and the communication range was eight miles. In July of the following year, 1898, Marconi proved that two-way communication was possible by transmitting in the reverse direction (from ship to shore), the results of the Kingstown yachting regatta to Dublin. The ship was the *Flying Huntress* and this incidentally was the first commercial radio transmission, and it was paid for by a national newspaper.

The early days of marine radio were packed with dramatic incidents which served to emphasize the importance of the new communication medium. Radio has been used since its earliest days to fight crime and in July 1910 Captain Kendall of the Canadian Pacific liner *Montrose* bound for Quebec from Antwerp suspected that two of his passengers, a Mr. Robinson and his son were, in fact, Dr. Crippen and Miss Le Neve, wanted for murder in London. He sent a wireless message to Liverpool stating his suspicions and Inspector Dew of Scotland Yard embarked on the much faster White Star liner *Laurentic* which overtook the *Montrose*. Eventually with further wireless aid, Inspector Dew boarded the *Montrose* dressed as a ship's pilot and made the arrest.

Even more dramatic was the story of the *Titanic* in 1912. At about that time Wanamaker's, the big New York store, decided to install the most powerful radio station that could then be designed. A young man, twenty-one year old David Sarnoff became the station's first operator. On the night of April 14th, as he was sitting at his instruments on the roof of the Wanamaker store he picked up this startling message:

'S.S. *Titanic* ran into iceberg. Sinking fast.'

For the next seventy-two hours, the young Sarnoff sat continuously at his post, straining to catch every signal that might come through the air, a feat which demanded an expert operator in those days of primitive equipment. By order of the President of the United States, every other wireless station in the country was closed down during the emergency to stop interference.



Fig. 1. 1912. David Sarnoff at the key of the Wanamaker Radio Station in New York.

Of the passengers on the *Titanic*, 1,517 were lost. Huddled in boats, clinging to wreckage were 706 survivors. The drama of this struggle against the sea caused millions throughout the world to grasp at every word that came via the Wanamaker station. Not until he had given the world the name of the last survivor, three days and three nights after that first message, did Sarnoff call his job done.

David Sarnoff later became the Founder and President of the Radio Corporation of America and an acknowledged leader of the American electronics industry.² Ever a close friend and supporter of the Institution, he was made an Honorary Fellow in 1944.

The loss of the *Titanic* and the great service which radio had performed aroused public consciousness to the need for this new means of communication. In the United States, Congress passed laws to enforce strict requirements in respect of the equipment and operators on seagoing vessels, and the industry began to assume a prominent place as a vital service.

In Britain, official recognition came in 1914 in the Mercantile Shipping Bill which laid down that every British ship which carried 50 or more persons and travelled more than 150 miles from the coast must have a suitable wireless installation. In 1916 every British vessel of 3000 tons and over had to be fitted and in 1917 it was extended to all merchant vessels above 1600 tons.

Marine radio communication made rapid progress in these early days because the need for communication with ships for safety purposes was very great. There were additional reasons however. The technology at that

period was limited to comparatively low frequencies whose transmission required large antennas which could be accommodated without too much difficulty between the ships masts. Moreover the propagation of such frequencies was exceptionally good over water. Thus, not only was marine radio badly needed, it could also be made to work relatively easily and with simple equipment. These were essential requirements for ships which sailed the oceans of the world often without touching port for many months at a time.

No such simple technical solutions were to hand for communication with land vehicles. Large antennas were impracticable and propagation of the low frequencies then available is relatively poor over land, while, the long waves involved do not readily penetrate built-up areas. In addition very few frequencies were available for any appreciable development of land mobile services. Early attempts were made to fit road vehicles but these had very limited success and many years were to pass before land mobile radio was to 'take off' like its marine predecessor. One or two attempts were made to fit vehicles before the first World War and serious interest was probably first aroused with the arrival of the tank during that war. In the meantime the interest in crime prevention was stimulating police interest in the wireless medium but the technological difficulties were still formidable.

Early Police Wireless

Despite these difficulties, by the 1930s some of the larger cities in Britain had installed medium-frequency transmitters operating around 2 MHz, which transmitted one-way services to police cars. The transmissions were hand morse, with some limited attempts to use telephony. These services were severely handicapped by high noise levels, fading and long distance interference



Fig. 2. 1920. This vintage police car was equipped with its large antenna to provide mobile communication for the police.

and were of limited value even to the few cities which were fortunate enough to get a frequency or, more usually, the share of a frequency.

One remarkable pioneer police installation was put into service in 1932 by the Brighton police. In this system foot patrol policemen were equipped with 'lightweight' receivers (4 lb!) operating on 2.03 MHz. The receivers worked remarkably well but the frequency limitations made a widespread development impossible. Brighton shared a channel with Glasgow and at night the Brighton patrolmen would receive fascinating but to them quite useless messages intended for Glasgow patrol cars. The idea was good but it was not for another 35 years with the introduction of the u.h.f. pocketphones that foot patrol radio suddenly became an indispensable part of the beat policeman's life.

The First V.H.F. Systems

With the approach of the 1939 War, the British Government became concerned that police m.f. transmitters might serve as beacons to enemy aircraft and plans were evolved to see whether frequencies in the region of 100 MHz could be used for police mobile communication. The possibility was not viewed with much optimism because it was believed, not unreasonably, that v.h.f. waves would be screened by buildings even more severely than m.f. transmissions. Nevertheless, a development programme was undertaken jointly at first by the Post Office and the Home Office in the hope that any communication might be better than none.

It was fortunate that some remarkable pioneer equipment design work had been carried out by the GEC at Coventry in the late 'thirties which had resulted in what were probably the first ever crystal-controlled v.h.f. transmitters and receivers working between 80 and 130



Fig. 4. 1940. The author on the first Home Office v.h.f. survey. The 100 watt transmitter was designed by GEC and worked on frequencies between 80 and 130 MHz.

MHz. The equipment was very large by modern standards and occupied the entire luggage boot of the car, but it was effective and in its simple ability to communicate it was comparable to the best mobile equipment available today. The same basic equipment designs were used in *Spitfires* and *Hurricanes* and later by all allied aircraft and proved to be far in advance of enemy airborne radio.

With this equipment the Home Office embarked on a comprehensive series of surveys throughout Britain in which all the larger cities and towns were tested for two-way coverage. Much to the surprise of all concerned, it was quickly found that provided the main station was well sited and had a commanding view of the area concerned, excellent telephony was possible over ranges of 15 to 20 miles both to and from the car. The fixed station power was 100 W and the mobile about 10 W. An initial fiat that fixed stations were not to be sited on premises other than police stations, which were always in the centre and lowest part of the town and as a consequence bad sites, was ignored by the enthusiastic development team in the best Nelson tradition!

The Spread of V.H.F.

Before and during the War, because of the very small number of available frequencies, radio communication was available to Government users only. The coming of v.h.f. opened up much wider possibilities however and in 1948 the first non-government mobile radiotelephone system in Europe was installed in the vehicles of a Cambridge taxi company. The installation was carried out by Pye Telecommunications who were to become



Fig. 3. 1932. The world's first police portable receiver developed by the Brighton police. Complete with bell calling it was far ahead of its time. A modern digital 4 oz (113g) paging receiver capable of decoding any of 2 million different codes is shown for comparison.

pioneers of the new development. Today, 27 years later, Europe has about a million vehicles using radiotelephones with some 200,000 in the United Kingdom alone and these are used for almost every conceivable application in central government, local government, industrial and commercial fields.

Twenty-seven years ago the idea of mobile radiotelephone was very novel and even in fairly obvious applications like ambulances, it was greeted with much scepticism. Strangely the ambulance authorities seemed lukewarm to the suggestion that communication with ambulances might save life, (it would have been a godsend during the War). When it was discovered however, by the West Riding of Yorkshire authority, that four ambulances with radio could do the work of five without and save a corresponding amount of money, the development took off and by the early 'sixties radiotelephones had become a standard fitting to all ambulances.

Electricity and gas authorities were to become amongst the biggest users (25,000 in the United Kingdom today), the first vehicles being fitted in 1950. The Automobile Association was also an early user for its breakdown service and began fitting in 1949. It now has a fleet of some 2500 radiotelephone equipped vehicles.

One of the remarkable features of these mobile services has been their high growth rate, usually about 15% per annum, the numbers thus doubling every five years. It is a matter of some debate how long such a growth rate will be maintained and of course the answer is not known with certainty. Much will depend upon licensing policies and the availability of adequate frequency space.

This rate of growth has been accompanied by dramatic improvements in equipment design and technique. Whereas transmitter power and receiver sensitivity are much the same as they were in 1940 nearly all other parameters have been substantially if not radically improved. The most spectacular single improvement lay in the replacement of the thermionic valve by the transistor. Fully solid-state transmitters and receivers began to take over in about 1960. The most important single contribution of this change was to reduce the fault rate of a mobile equipment from about four faults per year to one fault per year. Great improvements in quartz crystal design and manufacture have also taken place over the period and mobile radio as we know it today would not be possible without the remarkable advances in the performance of quartz crystal oscillators and quartz crystal filters.

Despite the improvements in equipment design and the reduction of cost in real terms, the present level of about 2% of all vehicles fitted with radiotelephones seems very low and a good case can be made for envisaging between 10% and 20% before any degree of saturation is reached. If the cost of running and fuelling vehicles continues to escalate over the next twenty-five years, it may well transpire that in time radiotelephones will become compulsory for all land vehicles as they are at present for all but the smallest aircraft and ships.

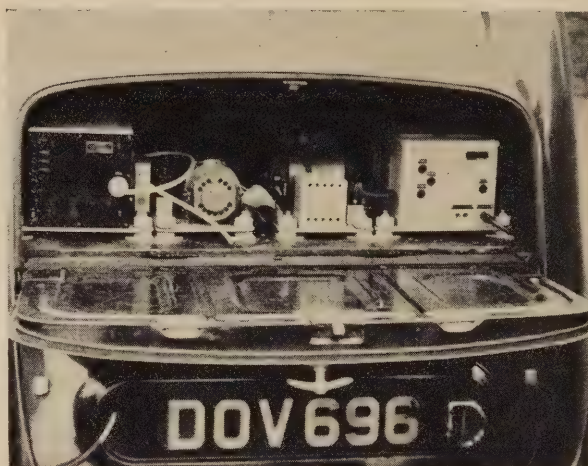


Fig. 5. 1945. A boot-mounted mobile installation designed by GEC. The transmitter and receiver were in separate boxes and the h.t. power unit was a rotary converter. The equipment occupied the entire boot of the car.

Frequency Allocation

The mobile radio industry is quite unlike any other branch of electronics in that frequencies are an essential ingredient of the products. Without frequencies there can be no product and no market. Only if there is an adequate supply of frequencies and only if these are in turn well administered can there be an efficient and prosperous industry to supply the continually expanding needs of users. This requirement makes it inevitable that there should be well developed co-operation between the government allocating the frequencies, the users who employ them and the manufacturers who supply the equipment. The mobile radio industry has therefore to co-operate with government and its users in far greater depth than most branches of the electronics and other industries. When v.h.f. arrived on the scene in the early 'fifties, no such co-operative machinery existed. This situation led, after much debate† to the establishment in the United Kingdom in 1954 of a government-sponsored Mobile Radio Advisory Committee through which government, users and industry representatives confer on important policy considerations such as the introduction of new frequency bands and new channelling standards.

The evolution of frequency allocation policy and the actual allocation of frequencies are to say the least complex matters and the British administration has developed along both flexible and sensible lines to the advantage of all concerned. Such administration is evolutionary and needs continuous improvement. A recent interesting innovation is the use of a computer to record the vast number of channel assignments and to suggest optimum assignments for new users. Computers are also being used for mobile coverage prediction.

† In 1955 an aggrieved user complaining about the administration of frequencies won an action in the High Court against the Post Office on the grounds that appropriate regulations governing the use of mobile radio had not been laid before Parliament.

To meet the demand for more and more frequencies to cope with the rapid growth of the industry, Britain has pioneered progressively the introduction of narrower channel spacing which in the v.h.f. band began at 200 kHz during the War and has been reduced successively to 100 kHz, 50 kHz (1957), 25 kHz (1961) and 12.5 kHz (1968).

One of the most important frequency allocation decisions ever made in the United Kingdom was the adoption of the idea of putting fixed transmitter frequencies in one channel block and mobile transmitter frequencies in a separate block some 5 or 10 MHz removed. This is known as 'double-frequency' allocation. The alternative method, in which transmitters and receivers, both fixed and mobile, use the same frequency, is known as 'single-frequency' allocation. To the uninitiated the single-frequency method would appear preferable because superficially it uses half the number of frequencies required by the double-frequency method. In fact the opposite turns out to be the case. One advantage of double frequency allocation is that a pair of frequencies can be allocated many more times than a single frequency because the base stations, which have high, fixed antennas, do not interfere with each other.

In the single-frequency case, fixed stations which are on the same frequency interfere with each other over great distances. Even more important the single-frequency transmitters in the same area give rise to high level intermodulation interference products which receivers are powerless to reject. Double-frequency operation avoids these difficulties and frequency allocation in the United Kingdom has been immeasurably simpler and more efficient as a direct result of its adoption. The adoption of single-frequency operation in the USA before its disadvantages were fully appreciated has led to the most difficult frequency allocation problems. As new bands have been opened at u.h.f. the USA has largely dropped this method.

The credit for pointing out the advantages of double-frequency allocation goes to Superintendent Frank Gee who pioneered the Lancashire Police v.h.f. system in the late 'thirties and who suggested it to the Home Office in 1944, the Home Office subsequently recommending it to the Post Office. Mobile radio services in Britain and the many parts of the world, which followed British policy in this matter owe him a considerable debt.†

The Great A.M.-F.M. Controversy

No doubt all great innovations have their areas of controversy. In mobile radio the chief contention has centred around rival modulation systems, amplitude modulation and frequency modulation.

British users and manufacturers were well committed to the use of a.m. before f.m. equipment on the relevant frequencies became available. When f.m. did

make its appearance a remarkable controversy broke out on the respective merits of the two systems. The controversy began in 1945 and is not even entirely ended today, thirty years later. The arguments had and still have a strong commercial bias. No manufacturer wants to carry two versions of equipment, one a.m. and one f.m., and each company has tended to polarize on the system which suited his particular commercial circumstances. The result has been a sustained and vehement argument about the two systems, whose performance differences, in the main are distinctly marginal.

Amplitude modulation did have one indisputable advantage. It was shown by the Home Office in 1945 that when the area to be covered exceeded the range of a single station, then the range of the system could be extended by using several fixed transmitters on the same channel but with very closely spaced carriers. The system which became known as multi-carrier a.m. was widely adopted for police and aeronautical communication.^{3,4} The fact that there was no equivalent method of using f.m. served to fuel the fire of the a.m.-f.m. battle.

The a.m.-f.m. controversy has not been without value. It stimulated the development of better equipment on both sides. The retention of a.m., still the dominant system in the v.h.f. bands, certainly contributed to the early introduction in the United Kingdom of 12.5 kHz channelling to the great benefit of the users in terms of greater channel availability.

When the u.h.f. bands were opened up in the 1960s, manufacturers opted out of carrying two ranges of equipment and settled quietly on f.m. as standard. The standard use of f.m. in the u.h.f. band has however not stimulated the introduction of narrower channelling at u.h.f. where 25 kHz is still general, in spite of the fact that it was shown very clearly in 1970 that provided low-ageing quartz crystals are used, 12.5 kHz channelling at u.h.f. is entirely practicable.⁵ The failure to introduce 12.5 kHz channelling at u.h.f. with the same promptness with which it was introduced at v.h.f. in 1968 represents in my opinion, a presently lost opportunity which successive generations of users will not appreciate when they run out of u.h.f. channel capacity so much sooner than might otherwise have been the case.

Personal Portables—The Pocket Radiotelephone

The Brighton Police pioneers of the thirties clearly had the idea of personal radiotelephone imaginatively conceived. True, their set was a 'receiver' only and they must have viewed the prospect of a two-way pocket set as remote indeed. That particular cake was to take another thirty-five years to bake. The vital ingredients were the transistor with its tiny size and small power consumption and the miniature monolithic quartz crystal filter which provided the highest receiver selectivity in a tiny package. These component developments did not occur overnight and indeed it is interesting that when the Brighton sets were first operated, primitive quartz crystal filters had already appeared and the transistor had been conceived but not realized.

† Since drafting the paper I have learned that Professor Dan Noble who pioneered f.m. mobile communication in the USA was an early advocate of double frequency allocation for police systems. The FCC were not persuaded at that time however towards its wider adoption.

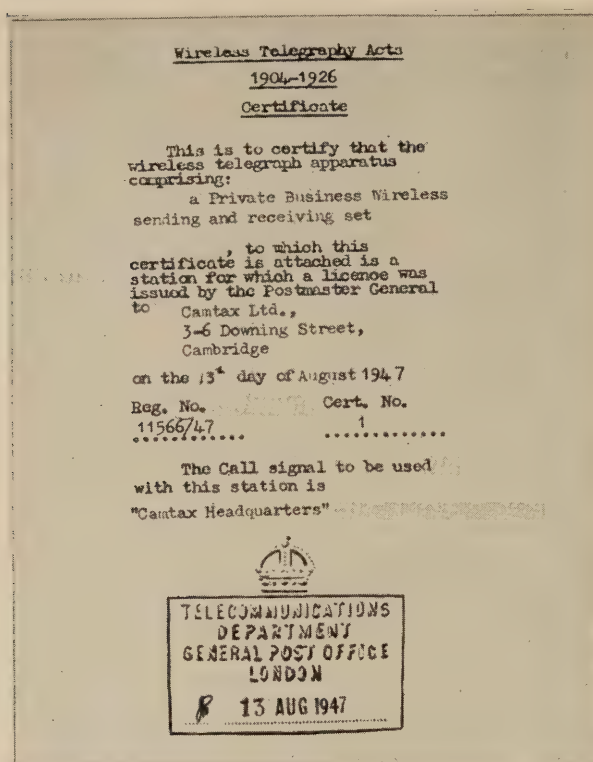


Fig. 6. 1947. The first British Government licence issued for private mobile radio. Today, 28 years later, the Post Office issues some 20,000 licences per year.

As always, a main problem was to get a really small antenna, small enough to go in the pocket and yet capable of radiating efficiently to base stations over a radius of several miles. The elegant solution came in the 1960s with the development of u.h.f. in the 450 MHz band with the tiny antenna that this made possible. An outstanding example was the Pye pocket radiotelephone (1964) introduced first for police service and later for every conceivable application where hand-held communication is beneficial. Some 70,000 of these portables are in everyday use today in the UK. There are some 1000 personal portables in use at London Airport alone. When it is considered that there are 50,000 people employed at that site, the number now fitted must surely be a very small fraction of the number of those who could benefit from pocket communication.

The pocket radiotelephone must have an immense and still largely untapped future in wider fields. It does not take too much imagination to look at the hand-held calculator with its miracle of digital processing to envisage it complete with built-in transmitter and receiver giving full access to the public telephone network. I believe this will be one of the great new mobile developments of the next decade.

The use of personal portables is growing at an explosive rate and may well catch up and pass the numbers used in vehicles. As in the case of the vehicle application the demand for frequencies exceeds supply but the use of radiating cable or leaky feeder systems may help to

solve this problem in the future. One of the most remarkable systems of this kind has been installed in the London Stock Exchange. In this scheme 400 stockbrokers can speak instantly to their offices over 103 channels spaced at 12.5 kHz in the 450 MHz u.h.f. band. Radiating cable enables excellent two-way coverage throughout the vast building complex yet confines interference to a radius of about half a mile.

Radio Paging

Concurrently with the development of two-way radio communication, there has been a remarkable development of radio-paging equipment and services. The first paging systems were established in the mid-fifties using a magnetic loop around the building to be served and operated on very low frequencies around 70 kHz. One of the first of these systems was installed by the Multi-tone Company at St. Thomas' Hospital London, in 1956.

Later the technique changed to v.h.f. radiating system using frequencies in the 27, 150 and 450 MHz bands. Development is now very widespread with over 2000 systems and 100,000 paging receivers in use in Britain alone. The receivers involved are very small, weighing only a few ounces.

These systems are mainly privately operated and normally give coverage over the user's site and premises only. More recently however with new techniques an important new development has become possible whereby whole cities or even countries may be covered to give a radio-paging service to the public at large via the public telephone network.

The British Post Office opened a trial system of this kind in the Reading area in 1973 and are planning to open a major system covering the whole of Greater London in 1976. Ten computer-controlled transmitters are planned to give coverage of the entire metropolitan area with satisfactory operation on the inside as well as outside of buildings.



Fig. 7. 1964. This u.h.f. radio telephone, the Pye pocketphone, represents a breakthrough in portable radio.



Fig. 8. 1974. Twenty-nine years of progress. This v.h.f. mobile by Storno mounts under the dashboard and represents a reduction in size of about 40 times compared with its 1945 predecessor (Fig. 5).

By employing large scale integrated digital logic, the receivers to be employed in these new systems can discriminate between up to 2 million different address codes. All this in a receiver weighing about four ounces and working for three months from a 1.5V pen-light cell!

Public radio paging promises to take the prize for the most economical use of frequency space. With the new high speed digital techniques now available it will be possible to design a system to cover the whole of Britain catering for a million users all on the same v.h.f. 25 kHz channel!

Public Radiotelephone Service

One of the more disappointing features of the last 25 years of mobile radio has been the slow development of public radiotelephone services for individual users. Fleet users of vehicles have been well catered for with a relatively plentiful supply of channels either on a shared or, for the more fortunate, on an exclusive basis. The individual user who cannot afford or does not want his own base station and who may want to contact any of a number of fixed addresses, has not fared as well. A further class of user not adequately served is the long distance vehicle operator, requiring regional or national coverage far beyond the capabilities of a single base station. Such users need what is known as a common carrier service, that is one in which the base stations are established by a third party licensed to provide such service. Radiotelephone service of this kind is offered by the authorized common carriers over a network of such stations to as many individual, or fleet operated vehicles, as the system's capacity will allow.

Common carrier services are of two main types. The first is offered by the telephone company or administration and gives the mobile user access, either through an operator or automatically, to the public telephone network. The second kind of service is generally called private common carrier and gives access to a message handling bureau whose operators handle messages for the mobile subscriber.

The demand for common carrier services must be potentially very great and there is in fact a far greater vehicle population in this category than in the private system category. Yet such systems as have been commissioned to date cope with only a tiny sector of vehicle potential.

The problems impeding the development of such systems have been technical, economic and administrative. There are strong signs that these problems are being solved and over the next decade I would expect to see major strides being made in this field.

Of the two types of common carrier scheme, I believe the future must lie mainly with the telephone network coupled system with a fully automatic dialling mobile, if only because manual operation and message handling will be too expensive and difficult to provide on the extensive scale the future will require.

The Marine Radio Renaissance

Marine radio communication, so far advanced when the Institution was born, has not been subject to such dramatic growth and technical development as the land mobile field. The post-war period has seen the introduction of ship-to-shore v.h.f. communication on an international scale and more recently the widespread introduction of s.s.b. with a consequent improvement in channel availability and standard of communication.

The Institution's Jubilee Year may see, however, a most dramatic innovation, the introduction of a marine satellite communication system. In late 1975 or early 1976 two communication satellites, one over the Atlantic and one over the Pacific, each part of the Comsat Corporation's new *Marisat* system, are due to be launched and commissioned. The new system is planned to give speech, telex and data communication to ships throughout the world on a 24-hour on-demand basis. Marconi and Sarnoff would have been fascinated by this resurgence of high technology in the field that established them both as future leaders in the world of radio communication.

Airborne Radiotelephone

The history of airborne radiotelephone communication was influenced radically by the development of v.h.f. and the great advantages which v.h.f. offered in terms of low noise levels, stable propagation and small antennas.

Prior to 1939 airborne equipments were in effect airborne versions of marine m.f. designs and the communication offered was of limited quality and uncertain behaviour. The outstanding breakthrough in air-ground communication came about in 1939-40 when modified 4-channel versions of the equipments designed by GEC for the Home Office police service were fitted in the first *Spitfires* and *Hurricanes*. The equipment, the TR1133 and TR1143 proved to be outstandingly effective, far more so than the corresponding enemy equipments which were still operated on m.f. The contribution made by these v.h.f. equipment to British air defence was outstanding, perhaps as crucial as radar if not so spectacular.

Subsequent post-war development on airborne radiotelephones has been towards synthesized v.h.f. equipment giving 720 channels for civil use and synthesized u.h.f. equipments giving 3500 channels for military communication. Excellent though these equipments are, their range of operation is limited to horizon distance and this led to the adoption of the same multi-carrier system used by the Home Office to extend operating range beyond the capability of a single station. This was really possible because all airborne v.h.f. and u.h.f. systems have always used amplitude modulation and it is interesting to note that the a.m.-f.m. controversy never seriously arose in this field.

The line-of-sight range limitation of v.h.f. still creates some difficult communication problems for aircraft, particularly over the world's major ocean routes. The final solution to this outstanding problem may come, as in the marine case, by satellite communication and a programme to establish L-band satellite communication for aviation services is now being proposed.

The Future

Land mobile radio as we now know it 'took off' in the immediate post-war period and is now drawing to the close of its first generation of mature development. It can claim impressive achievements in its first thirty years. Vast numbers of important government, industrial and commercial services now benefit from its unique ability to give instant communication with people on the move.

But what of the future? With only 2% of all vehicles fitted it certainly cannot claim to be giving comprehensive service to the nation's transport. Its public radiotelephone services are miniscule and there is even a waiting list of tycoons who cannot get on the service. We are still a long way from comprehensive radiotelephone systems readily available to the general public.

Mobile radio, moreover, as we now know it, was conceived in an era of abundant transport and cheap oil. That era is rapidly drawing to a close and as it does mobile radio must broaden its outlook and adjust to a very different environment. In the years which lie ahead many kinds of travel will be replaced by high

grade telecommunication services and the indispensable transport and travel services remaining will have to be serviced by the most efficient and modern forms of mobile communication. The demand for the wider and more comprehensive mobile radio services will be augmented by these new forces. Both government and industry should respond by planning now to meet the increased need as it arises.

Acknowledgments

I am indebted to the Radio Regulatory Department and to the Directorate of Telecommunications of the Home Office, also to the Directorate of Communications of the Post Office for information on the development of Mobile Radio. Valuable information on early police wireless was also obtained from the London Metropolitan Police and the Sussex Constabulary.

The following organizations and commercial companies were most helpful in providing information and illustrations of early and modern radio equipment: The Automobile Association, The Joint Radio Committee of the Nationalized Power Industries, GEC-Marconi Electronics Ltd., Multitone Ltd., Pye Telecommunications Ltd., RCA of Great Britain Ltd. and Storno Ltd.

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Television reception 1925—1975

D. W. HEIGHTMAN, C.Eng., F.I.E.R.E.

The development of efficient cathode-ray tubes was the key to the initiation of television broadcasting. Typical circuits and their evolution both for monochrome and for colour are described, reference also being made to the problems of standards. Future developments such as video recording, Teletext and cable television are reviewed.

The 50-year period from 1925, which saw the birth of our Institution, and continuous progress up to the present day 1975, also almost exactly corresponds with the growth and life story of television.

True, a few earlier researchers or visionaries—notably:

Nipkow (Russia) 1884—scanning disk;

Rosing (Russia) 1907—use of c.r. tube as receiver;

Campbell Swinton (UK) 1908—fundamental principles of electronic television;

foresaw or were working on early forms of picture transmission and reception. However, the years 1923–29 saw the first practical work by Baird and 1929 the first BBC m.f. transmission of the primitive 30-line Baird system.

Subsequently, television receiver developmental phases were broadly related to milestones set by the availability of suitable transmissions, the history of which is being dealt with in more detail in Mr. Steele's paper in this Jubilee issue of the Journal. For the sake of completeness, however, the dates of the major events are set down in Table 1.

To give individual credit to the many engineers and companies, both in the UK and internationally, who made major contributions towards the progressive development of the television receiver as we understand it today, including colour, would be well nigh impossible. By its nature and complexity, much of the engineering development has essentially been the result of team-work amongst many specialists.

Mr. Denis W. Heightman (Fellow 1948, Member 1942) is Group Technical Director of Thorn Television Rentals Ltd. He has been in the radio industry since 1928, starting as an engineer with Broadcast Relay Service Ltd. From 1938 to 1950 he was Managing and Technical Director of Denco (Clacton) Ltd. and from 1950 to 1956 Chief Television Engineer of English Electric Company, Liverpool. For the next five years Mr. Heightman was Technical Director with the Radio Rentals Group and from 1962 to 1965 he was with the Relay Exchange Group, returning to Radio Rentals when the two companies merged in 1965.

Mr. Heightman has served on numerous Institution Committees and from 1968 to 1970 was a Vice-President. He was for 5 years Chairman of the Radio Trades Examination Board and he serves on technical sub-committees of the National Electronics Council. His long-standing interest in amateur radio included pioneer experimental work on v.h.f. propagation, a paper on which gained him the Institution's Clerk Maxwell Premium in 1950.

However, accepting that some important omissions may well be made, reference will be made to a few who made vital contributions, particularly in the early days, confirmed by subsequent history.

The Cathode-ray Tube

More than any other single item, the availability and development of the cathode-ray tube has set the main pattern of receiver development over the years.

The early work by Braun (Germany 1897); Wehnelt (1904); Johnson (USA 1921) and Von Ardenne (Germany 1930) led to the use of early gas-focused tubes first for television purposes in the UK in the 1930s. By 1935 electrostatically focused hard tubes superseded these early tubes. These tubes also had electrostatic deflexion by internal plates, shortly to give way in 1936 to magnetic deflexion by external coils—in use to this day.

Important future discoveries related to ion burn of the face phosphor which was recognized and first cured by the fitting of the ion trap magnet and offsetting the gun by approximately 10° from the central axis of the tube. Later, this problem was overcome by 'aluminizing', i.e. coating the inside of the tube phosphor face with a thin coat of aluminium. This process was first devised to increase the tube light output by reflexion but was also found to stop the effects of ion bombardment and is retained even in modern colour tubes.

Figure 1 shows a 1936 vintage electrostatically focused and deflected tube, whilst Fig. 2 illustrates the development of the monochrome tube from 1945 to 1965. Finally Fig. 3 represents the 1975 state of the art with a 110° , in-line gun, vertical stripe colour tube compared to an earlier delta gun tube requiring complex convergence assemblies and setting up.

Many attempts have been made to find successful alternatives to the cathode-ray tube, but in general conception it has reigned supreme for 50 years and is likely to continue for another 20 years as the main means for presenting television pictures. One day, the frequently talked of 'flat' picture reproduction device will become a reality to reduce the bulk and weight of the television receiver; also to avoid the optical disadvantages of the cathode-ray tube frontal glass.

Considerations of the size, the awkward shape and considerable weight of the cathode-ray tube have, over the years, also dictated the cabinet layout, into which

Table 1

Television Receivers 1925–1975: Main events affecting Design and Production in United Kingdom

- 1925 Baird demonstrated his equipment at Selfridge's, London; the first public demonstration of television. Zworykin (USA) working on iconoscope and cathode-ray tube receiver—in 1921 was granted US patent for electronic television.
- 1929 (September) Baird 30-line from BBC until 1935.
- 1931 EMI Isaac Shoenberg appointed Director of Research on television; G. E. Condliffe, A. D. Blumlein, C. O. Browne and P. Willans team members. L. H. Bedford joins Cossor for c.r. tube development.
- 1932 O. S. Puckle commences television receiver development work at Cossor. J. D. McGee joins EMI for c.r. tube development.
- 1934 Formation of Marconi-EMI Ltd. joint company to exploit television in v.h.f. band.
- 1935 Demonstrations of 405-line EMI and Baird 240-line systems to T.A.C. Technical Sub-Committee.
- 1936 BBC first trials of 'high definition' television on v.h.f. (2nd November) Start of world's first regular high definition television service.
- 1937– Domestic receivers now marketed by: Baird, Cossor, Ekco, Ferranti, GEC, HMV, Marconi, Murphy, Philips, Pye, RGD and Scophony.
- 1939 20,000 receivers in use. (September) BBC Television closed down. No television for period of war.
- 1946 (7th June) Television started up again on 405-system v.h.f. (Industry in a hurry—should have chosen a new system at this stage!)
- 1949 Extension of BBC1 to cover UK on v.h.f. with 405 lines begins.
- 1950 American NTSC began investigations into colour systems. RCA demonstrate 3-beam shadow-mask colour tube.
- 1952 1.5M monochrome televisions in use in UK.
- 1953 (July) USA NTSC signal specifications completed.
- 1955 (22nd September) First London ITA programmes on Band III v.h.f. 405 lines.
- 1960 Television licences now 10M+.
- 1961 (May) IERE makes recommendations to Pilkington Committee on Broadcasting.
- 1962 W. Bruch, Telefunken, Germany, introduced PAL variation to NTSC colour system. (July) Government White Paper announces decision on 625-line standard and use of u.h.f. (No decision on colour system.)
- 1964 BBC2 u.h.f. 625-line monochrome transmissions commence from Crystal Palace.
- 1965 U.h.f. services extended to UK (BBC1 and ITA).
- 1966 Government decision to use PAL 625 colour system.
- 1967 (July) First PAL colour BBC2 u.h.f. programmes.
- 1969 (15th November) Colour 625-line u.h.f. extended to London BBC1 and ITV.
- 1970– U.h.f. colour coverage 625 lines extended to remainder of country.
- 1971 By 1970 1M colour receivers exceeded in UK.
- 1975 Annan Committee on Future of Broadcasting consider many submissions from wide variety of organizations—including NEC.



Fig. 1. Cossor cathode-ray tube for television, 1936 vintage! 'This tube provides a brilliant black and white picture, 10 inches long \times 8 inches in height.'

the remaining 'electronics' and loudspeaker had to be accommodated.

Aesthetic considerations have also brought pressure over the years from the appearance and from set designers for reduction in the overall depth (from frontal face to end of neck) of cathode-ray tubes; hence the transitions from bulb angles of 50° , through 70° , 90° and 110° in monochrome tubes. With improvements in glass technology also, improvements in the faceplate shape to give 'square' corners, and the correct rectangular 4×3 picture aspect ratio became possible in the late 1960s. Circuit engineers in turn had to meet the more complex, powerful and exacting scanning requirements to reproduce geometry as satisfactory on the wide angle rectangular tubes as on the earlier narrow angle ones.

Colour television is now undergoing one of those angular transitions from 90° to 110° but wisely in the UK considerably longer time is being taken in effecting the change.

Particularly in the USA, much research was done in the early post-war years in attempts to evolve a practical

colour picture tube. In this connection outstanding was the determination of David Sarnoff, Head of RCA, to ensure that, with enormous expenditure, their research laboratories in 1950 eventually produced the first successful design for mass production, the shadow mask triple-gun tube, based on proposals by A. N. Goldsmith and A. C. Schroeder. This tube, made under RCA licence, subsequently formed the basis for all the first colour television receiver production in UK, Japan, Europe and other countries throughout the world. Many thought that such a complex scientific device could never be mass produced successfully—but a miracle of production technology has proved them wrong.

Whilst the shadow mask tube was under development, a few laboratories and engineers, notably Dr. E. D. Lawrence of USA, were also experimenting with variations of tubes using horizontal and vertical striped phosphors instead of the dot 'triad' arrangement in the RCA tube. However, for a variety of reasons, more connected with gun and shadow mask design considerations, none of these concepts at the time proved a successful alternative to the RCA tube.

After the shadow mask tube had been firmly established in receiver mass production for several years, Miyaoka of Sony (Japan) in April 1968, came up with a successful, though small size stripe screen tube called Trinitron used in their own receiver production. This tube had one main gun, but three separate cathodes *in line*, side by side (with a common grid assembly), simultaneously scanning each stripe. An aperture grille was used instead of the shadow mask. This consisted of

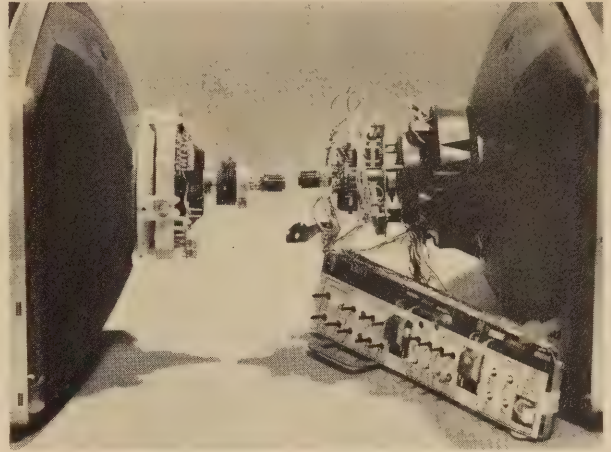


Fig. 3. Comparison of the 110° neck components of the self-converging Thorn Precision In-line tube with the neck components and convergence circuits of a conventional delta-gun 110° tube.

vertical slits etched in a metal sheet. Receiver scanning circuit design was simplified because the need for vertical dynamic convergence of the three electron beams was obviated.

Colour tube laboratories in several parts of the world subsequently recognized the advantages of using an in-line gun arrangement (instead of the triangulated RCA gun arrangement), together with vertical phosphor stripes and further development work went on. This work resulted in 1972 with the appearance of tubes using separate but in-line guns and shadow masks with vertical slots, instead of triad holes which, with considerable changes in associated scanning yoke design, permitted pre-adjustment of convergence.

Now, in 1975, we are seeing the first successful mass-produced in-line stripe tubes in 90° and 110° angles and in all sizes up to 26 in (66 cm) diagonal. Although the reproduced picture has very little more to offer in terms of quality or geometry compared to a well set-up triad shadow mask, from a receiver production and service viewpoint the lack of complex convergence circuitry and multiple set-up adjustments are very worthwhile.

One further development should be referred to; namely, that which is referred to as 'black matrix'. First applied to triad dot tube face plates but now also available with stripe tubes, this development takes the form of a black non-reflective coating applied in the 'gaps' between the phosphor dots or between the stripes. The object is to reduce internal light reflexions which reduce the tube contrast ratio. In turn, the face plate no longer needs to have a reduced light transmission characteristic. The overall effect is an increase in light output of about 33½%.

With phosphor developments over the past five years, including rare-earths, plus black matrix colour picture tube, light output is now equal to the best monochrome tubes!

Such was the accuracy required in setting up the first colour tubes that engineers became aware of the effect of the Earth's magnetic field, as well as the proximity of other fields producing a deleterious effect on the 'colour



Fig. 2. Mullard television picture tubes from 1945-1964:
Top left: LW22-16, 9 in 64°, 14.6 in front to back.
Lower left: MW36-24, 14 in 70°, 16.6 in front to back.
Top right: AW43-80, 17 in 90°, 15.6 in front to back.
Lower right: AW47-91, 19 in 110°, 12.0 in front to back.

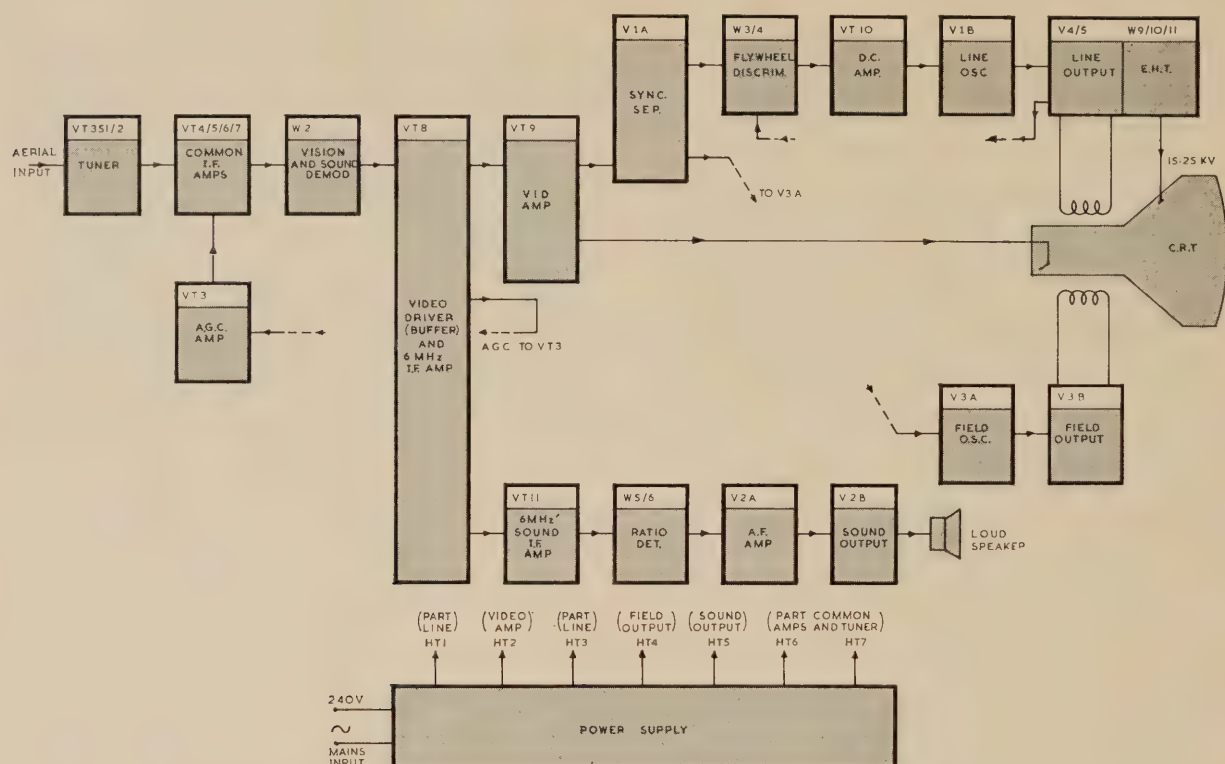


Fig. 4. Block diagram of typical monochrome receiver (625 line, single standard).

purity' by diverting the individual 'landings' of the three beams on the tube phosphor dots!

By the late 1960s colour tubes were fitted with 'degaussing' coils around the outer perimeter and suitable circuits to 'degauss' the tube each time the receiver was switched on. Magnetic screening plates are also fitted around the tube cones. As an additional facility to ensure optimum beam centring within the deflexion field adjustable magnets on the tube neck provide for initial 'purity' setting up.

Typical Television Receiver Circuit

The block diagram in Fig. 4 recalls the main functions of the television receiver. The cathode-ray tube scanning and e.h.t. supply will be dealt with first, followed by the signal circuits which provide the drive to modulate the tube.

Scanning, Synchronization and High-voltage Circuit Development

Scanning yokes

The first pre-war receivers used internal electrostatic deflexion plates for scanning purposes but this arrangement had several disadvantages and by 1936 progressively gave way to the system of magnetic deflexion by suitably shaped coils external to the tube neck. This system very much developed is still in use today. Much ingenuity has been required in developing the complex shapes of the line and field coils to give the best compromise between scan sensitivity, good geometry and deflexion defocusing.

The coming of ferrite cores, a development by Philips and Mullard based on earlier research, eased design

problems both in deflexion yokes and line scan output transformers.

With the arrival of colour television the scan coil requirements to simultaneously deflect three electron beams became even more complex and it also became necessary to use additional coil assemblies around the tube necks for the purpose of giving dynamic convergence correction, which requires suitable corrective currents to be applied to the coils.

For the latest colour tube designs of 110° stripe, in-line gun technology, there are two fields of thought in respect of the deflexion yoke design: (a) RCA who use precision toroidal windings on specially shaped and grooved ferrite 'cores'; (b) Philips, who keep to the developed saddle type. Further differences in tube types result from the fact that RCA use a tube neck diameter of 29 mm and claim better convergence with the closer spaced beams, whilst Philips use the 36 mm diameter.

Time-bases

For many years a ripe field for innovation by development engineers was the problem of producing correctly shaped current/voltage waveforms of sufficient volt-amps for the drives to the line deflexion coils of approximately 15 000 Hz and to the field deflexion coils of approximately 50 Hz. Blumlein, Puckle and Bedford are famous for early work in this field and the text book on the subject. With the time-bases operating satisfactorily, there was also the question of the synchronization of their speeds to the incoming signal with sync. separator circuits—again an area for much thought and innovation.

In the presence of electrical interference or noise level on low signal strengths, time-bases could be triggered erratically. Flywheel sync. circuits were introduced to obviate or minimize this problem. Ensuring good interlace of the alternate 50 fields per second has also been a problem not always solved even these days.

All this early work was done using valves—good old robust valves. With the promise of great things to come, over the past ten years and more particularly over the past five, the industry receiver laboratories have been involved in 'doing it all over again' with solid-state devices—following the early work done in 1948 by J. Bardeen and W. Brattain at Bell Telephone Labs. in the USA, i.e. using some of the (too) *many* varieties of transistors or allied devices. The anticipation was: less heat generation, more efficiency (i.e. lower power consumption); more compact layout, almost indefinite life and greater reliability at little or no extra cost.¹

Whilst in the low signal, low current parts of the circuitry, these advantages have been achieved, lessons are still being learned about the higher current and voltage applications met in time-bases, video drive and similar circuits. In particular, the e.h.t. environment of the colour tube of the order of 25–27 kV and its tendency to arc internally, and to produce damaging surge voltages in nearby circuits, presented a big problem in producing transistor failures. Tube connexions at the bases, etc., had to be provided with protective 'spark gaps' and these are now standard on colour receivers.

With the high scan currents required for 110° colour tubes, engineers had to realize that the heat generated at transistor or thyristor junctions can produce high temperatures. Heat sinks of larger and longer proportions are being fitted such that a set becomes reminiscent of a motor cycle cylinder with cooling fins in many places.

In the continuing search for greater reliability it can be said that electronic design engineers have almost invariably been too optimistic in their acceptance of high operating temperatures.

E.h.t. supplies to the tube

Very early receiver designs employed step-up transformers from 50 Hz mains to produce the 5–10 kV required, but from a safety point of view these devices were rather lethal. Valve high voltage rectifiers were also used. Other arrangements included 'ringing chokes'.

Before long it was realized that, because of the nature of the line scan waveform with a slow (relative) scan and rapid fly-back for retrace, high voltages were generated during the fly-back period at the anode of the line output valve. By suitably added overwinds on the line output transformer these fly-back voltages provided a useful and 'free' source of 10 000 Hz a.c. for e.h.t. purposes (15 000 Hz in the case of 625 lines). Similar systems are in use today even with transistor line drive circuits.

With colour sets particularly (25 kV) it has become customary to use voltage doublers or triplers of the Cockcroft variety in order to avoid the transformer e.h.t. insulation problems and only to rely on obtaining 8–10 kV from the line transformer itself. Valve rectifiers gave way

to e.h.t. selenium and silicon multi-element tubular rectifiers in this application.

Some early designs in this circuit area would have been regarded by electric power engineers as totally inadequate. In recent years, however, television receiver engineers have become more and more conscious of the problem of high voltage insulation and isolation in the confined environment of the television receiver.

'Front-End' Tuner, Channel Selection and I.F. Circuits

In the pre-1950 days with only one local television transmitter, tuning requirements were relatively primitive. Both the superhet and tuned r.f. systems were used and were more or less fixed-tuned to the one local station. Naturally the t.r.f. had to be stagger-aligned to produce the necessary band-width and band-pass characteristics.

The early 1950s saw switch or turret tuner designs begin to appear and gave the viewer the ability to select any one of up to thirteen channels in Band I and Band III, according to locality. As the ITA Band III v.h.f. network built-up, the switch or turret became a customer-operated control for programme selection—consequently electrical and mechanical reliability problems began to be experienced around this area in the receiver.

Tuners used fairly well-known circuits, first with valves for r.f., mixer and oscillator functions and, from the late 1960s, with transistors instead of valves.

With the confirmation of the change to 625-line transmission in the u.h.f. band during 1964 the third phase was reached and dual standard 405/625 receivers began to appear. These sets had both u.h.f. mechanical rotary, or push-button operation of tuning capacitor rotors, as well as v.h.f. turret tuners (together with complex standard-change switches!). The additional complexity and extra switch contacts did not help in the maintenance of reliability.

The fourth change began when the u.h.f. coverage of three programme channels was started on 625 lines in 1965. Single-standard receivers of simpler design for 625 and u.h.f.-only appeared, still using the mechanically operated push-button tuner. The reliability overall was better but there were mechanical re-set or stability problems in channel changing.

About 1968 the fifth phase commenced (after a great deal of research work by Philips/Mullard—amongst others) with the introduction of electronic or 'varicap' u.h.f. tuners instead of the earlier mechanical version. The nucleus was the 'varicap' diode or voltage variable capacitor of miniature proportion. This was a silicon junction device with capacitance variable by adjustment of d.c. bias voltage, originally introduced by Pacific Semiconductors, California, USA, in 1957. Tuners used 3 or 4 varicaps to 'tune' oscillator and r.f. circuits merely by simple switching of low d.c. voltages from a stabilized source. Receiver reliability was improved considerably, tuner faults being halved. Such tuners are now virtually standard in UK production. V.h.f. tuners using varicaps are also available.

Recent 'gimmickry' has extended to complex electronic 'touch-tuning' applied to varicap tuners (instead of the

use of light action switches) but, again, such complications do not make for improved reliability.

Remote Control

For the lazy or invalid, who do not wish to leave their armchairs to change channels, etc., ultrasonic compact remote control devices are now available. A small microphone on the receiver picks up the ultrasonic signals from the hand-held remote unit and associated circuits (mostly integrated) produce necessary control voltages for varicap tuner and other circuit variables including brilliance, volume and mains on/off.

Still further accessories, recently developed, provide visual indication, superimposed on the television picture, of (a) channel number selected and (b) digital time from a built-in i.c. clock unit.

I.f. circuits, first valve and then transistor in the early 1960s have not materially changed in basic circuit conception. The changes over the years have mainly been concerned with cost reduction and greater compactness—in common with the remainder of the receiver. With the change from the 405 system of positive picture modulation to the 625 negative modulation, various circuit changes had to be made in the associated a.g.c. and video detector stages.

Sound

The system change to u.h.f. also necessitated changes in the sound circuits to suit the frequency modulation of the 625 system instead of the old amplitude modulation of 405. Set designers then almost invariably adopted the circuit arrangement, called 'inter-carrier sound' (devised by R. B. Dome of GE, USA) which used the beat carrier resulting at the video detector (or video amplifier) output from the difference between the vision and sound carriers, i.e. 6 MHz in UK standard.

Conventional 'radio' sound circuits were used for the sound output drive to the loudspeaker. As with the remainder of the set, transistors eventually replaced valves for this function although many sets in use still use sound output valves.

The choice of loudspeaker by receiver designers has often left much to be desired, not only by hi-fi enthusiasts. Overall set cost considerations have generally restricted choice in this connexion but recently there has been a move to the use of better loudspeakers, especially in the larger cabinets.

Video Stages

Because of the adoption of compatible colour/monochrome transmission standards, most of the preceding review of technology is equally applicable to colour or monochrome receivers. From the video detector onwards (following the i.f. stages) the main circuit differences and additions occur in the colour receiver.

In monochrome receivers the video stages have gone through the transition from valves to transistors as have other parts of the receiver. The average monochrome cathode-ray tube requires a peak video drive between cathode and grid of the order of 50V for peak white.

Additional to this, the video amplifier stage has to handle the synchronizing pulses of ratio 25% of total signal, i.e. 65V overall. These relatively high voltage swings gave some early problems with transistor design but some reasonably reliable units have been available for the past five years.

In the case of colour tubes, the drive voltages are nearly doubled, hence the transistor presented more severe design problems, particularly from a reliability viewpoint.

Colour Development 1950-1975

The Long Period of System Development

In 1950 the National Television Systems Committee (NTSC) was re-formed, in the USA, of a group of engineers representative of several interested companies. The objective was to recommend a colour system compatible with the 525-line 60 field monochrome American standards in use. The outcome of the NTSC work, in July 1953, was the completion of the signal specifications for the world's first regular colour broadcasting which started in January 1954.

Ten years later in Europe and in the UK in particular, with the 625-line 50 field monochrome standard operational, work began with the objective of setting a colour standard for common use. The advantages of NTSC were recognized and formed the basis of the two revised systems—French SECAM (H. de France) and German PAL (Prof. W. Bruch)—which were devised to overcome the phase sensitivity disadvantages of NTSC.²

While these deliberations and tests were proceeding in the years 1960 to 1965, the industry television receiver development laboratories were anxiously awaiting guidance on the direction in which the UK would go for colour. At last, in 1966, the Government confirmed the adoption of the PAL system which time has proved an excellent choice and justified the long period of test transmissions.

Colour Circuits

The block diagram of Fig. 5 shows the main functions covered by the circuits peculiar to the PAL colour receiver. Much literature has been published on the complex functions and precise circuit details and it is not within the scope of this paper to do more than make brief comment.^{3, 4, 5}

The composite demodulated video signal containing luminance, colour and synchronizing information is presented to the decoding circuits of the block diagram. After processing, the output from the three (red, green, blue) separate video amplifiers of—100V approximate peak is taken to the cathodes of the R, G and B guns of the cathode ray tube.

In the earlier receivers it was customary to feed the tube cathodes with the $-Y$ luminance signal as in monochrome sets. The grids were then fed with the $R-Y$, $G-Y$ and $B-Y$ colour difference signals. RGB drive to the cathodes is becoming standard and is necessary for the new in-line gun tubes which only have separate cathodes, the grid being common to each gun.

The early vintage colour receivers of 1967 to 1970 used valves for the various decoding functions, but sub-

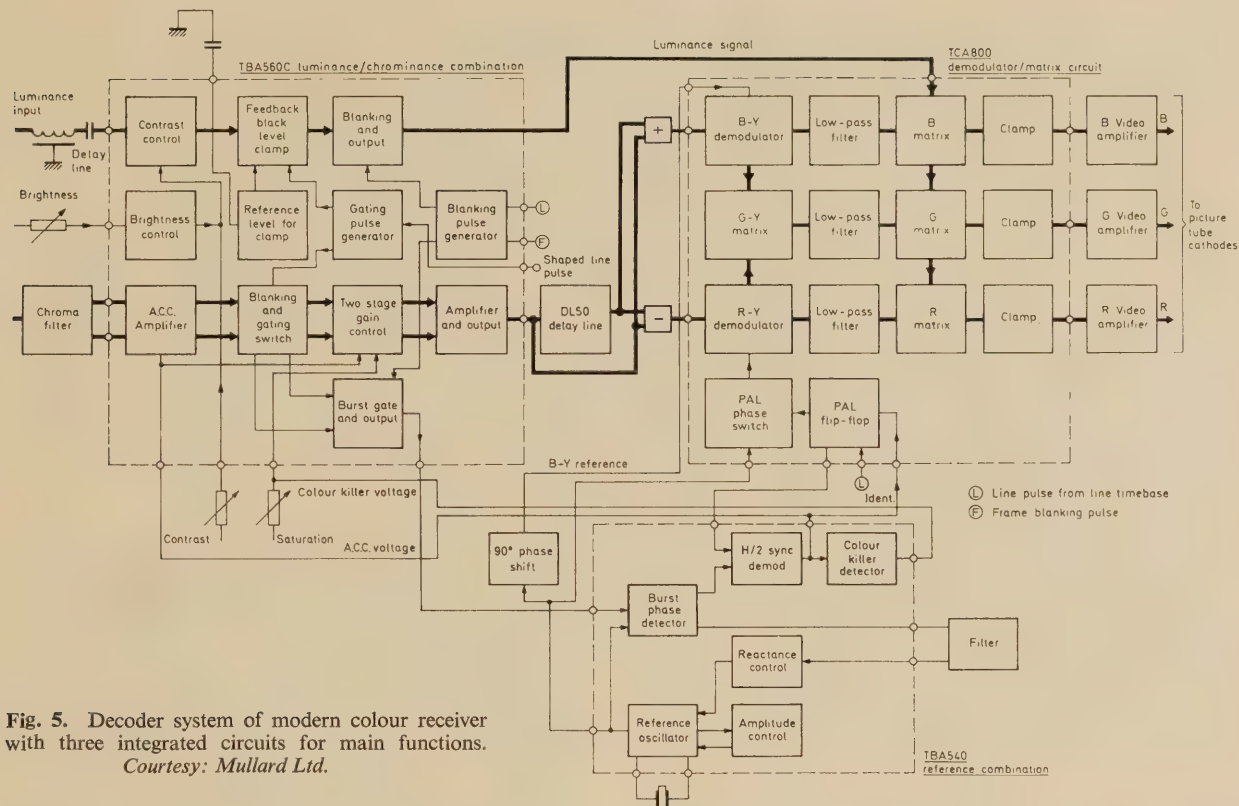


Fig. 5. Decoder system of modern colour receiver with three integrated circuits for main functions.
Courtesy: Mullard Ltd.

sequently nearly all stages were rapidly changed to solid-state discrete devices. The transition to integrated circuits for most stages except output drivers has now taken place.

Regulated Power Supplies

The move to solid-state devices for most circuits called for higher currents and lower voltages for most stages. At the same time a reasonable degree of voltage stabilization was required for several purposes and this has led to the universal use of regulated power supplies of various types. Favoured are switched mode or 'chopper' arrangements running at line speed, i.e. 15 kHz because reduced values of smoothing capacitors, etc. can be used. Some firms still retain the 50 Hz supplies with regulating thyristors, however.

Safety and Protection Considerations

In the past two years there has been a drive towards ensuring a greater factor of safety against fire and other risks and this activity has resulted in many, often costly, changes, both physical and electronic in receiver design. Various overload protective arrangements are now built in, including electronic automatic devices which reset if the overload disappears. European countries already have tough regulations and require test house approval before receivers can be marketed. In the UK the Safety Specification BS 415:1972 is likely to become mandatory this year.

The Coming of Integrated Circuits

Increasingly over the past four years i.c.s, covering several discrete component functions, have been sub-

stituted for small-signal, low-current, transistor stages.⁶ The main objectives have been: (a) more compact receiver chassis; (b) reduced assembly costs; (c) better performance in some cases. The main snags have been: (a) the long period of development to suit a particular circuit application; (b) the inflexibility of the mass produced i.c. once it is made; (c) the problem of ascertaining what are the causes of malfunctioning within such a compact and miniscule device; (d) the susceptibility to damage during receiver fault conditions and troubleshooting in a cathode-ray tube environment! (e) alternative sources of equivalent devices are often lacking—a position no production engineer likes.

However, despite the problems many i.c.s are now used including some multi-function devices. Areas of the receiver circuits covered include:

- (i) Synchronous vision demodulator (including a.g.c. and a.f.c.).
- (ii) Intercarrier sound demodulator/amplifier.
- (iii) Sync. separation and luminance combination.
- (iv) PAL switch, demodulator and matrixing.
- (v) Reference oscillator, colour killer, etc.

Thick Film Hybrids

Complementary to i.c.s in modern receivers is the use of hybrid circuits, where higher power dissipation is required, particularly in resistors. Built on thin alumina plates which have a good thermal conductivity, these compact assemblies also include some discrete components, e.g. capacitors and transistors as well as 'printed' interconnexions and resistors.

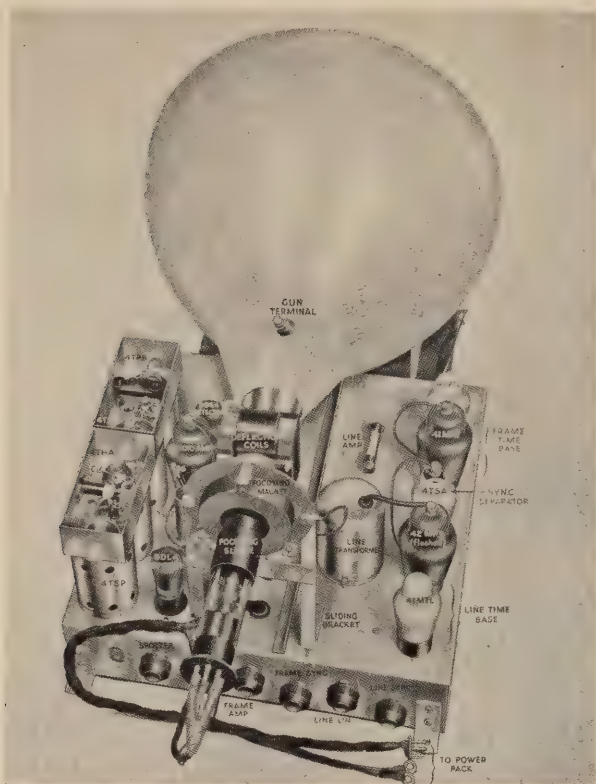


Fig. 6. Cossor 1210 1937/8. Monochrome receiver in three chassis. It is interesting to note that 80 of these receivers were, in 1938/39, the very first sets of millions later marketed by Radio Rentals!

Production and Mechanical Design Techniques

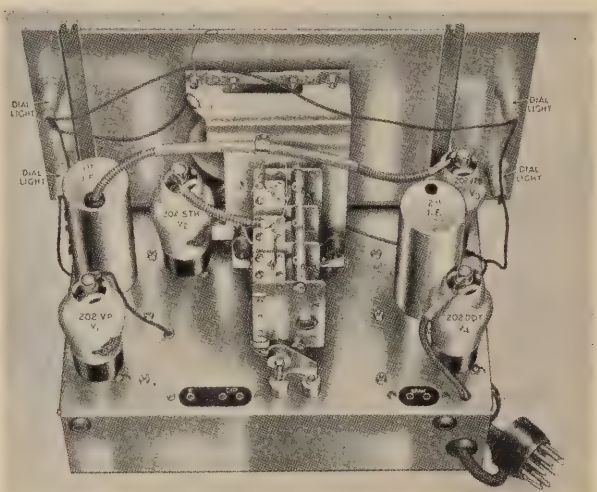
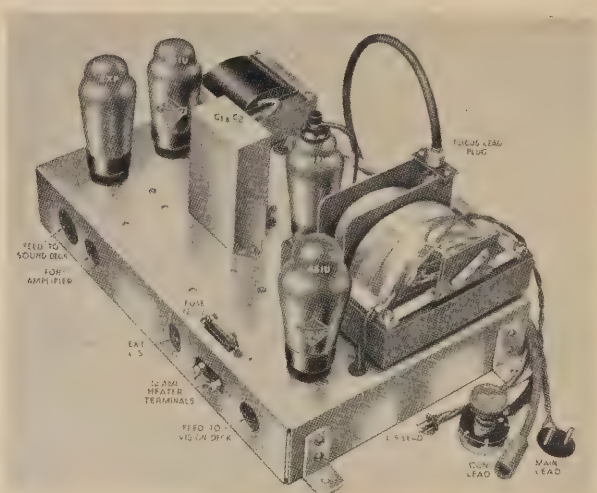
It is interesting to consider broadly, in a paper of this nature, what overall progress has been made by mechanical and electronic engineers in the period of nearly 40 years of monochrome television and eight years of colour.

Figure 6 illustrates the three chassis of a successful Cossor receiver of 1937–8 vintage driving a 15-in circular tube. Compare this with Fig. 7 which is the rear view of a Thorn 1975 colour receiver driving a 20-in rectangular in-line gun stripe tube. The volume of the monochrome Cossor chassis was probably about three times that of the 1975 colour chassis. Printed panels had not been heard of—they were introduced in the early 1950s—discrete wiring was used throughout—nice to trace but expensive. There were no transistors or i.c.s in 1938, whilst the 1975 colour set is fully solid state.

The weight of metal in the modern chassis, etc. will have been reduced by 3 or 4 times compared to the early sets.

The Cossor cabinet was probably substantially made with thick plywood and real wood veneers. The modern set will either have a fully moulded plastic cabinet (coated in *printed* veneers!) or an attractive simulated finish cabinet composed mainly of chipboard coated with p.v.c. imitation wood veneer.

Nevertheless, the combination of all these cost-saving devices has meant that despite inflation plus purchase tax and VAT a modern monochrome receiver costs no



more than a pre-1939 or post-1945 one and in real terms far less. (Motor cars have increased twelve-fold in price in that time.)

Probably in no other industry have design and production engineers been so constantly concerned with cost reduction! No other industry has been so adversely affected by the excessive stop-go policies of the Chancellors of the Exchequer since the war, which defy all logical planning.

Serviceability

Since the early receiver chassis were large, accessibility for service was no great problem. With designs becoming more compact, considerable attention, particularly for rental purposes, has been given to the need for easy access to all parts of the receiver. The colour set illustrated is shown with chassis slid out to the service position and, in turn, the panels hinge outwards for access. These panels may also be detached, as can other modules in the receiver for ready replacement in field service. The i.c.s are pluggable into sockets and power transistors also easily removed.

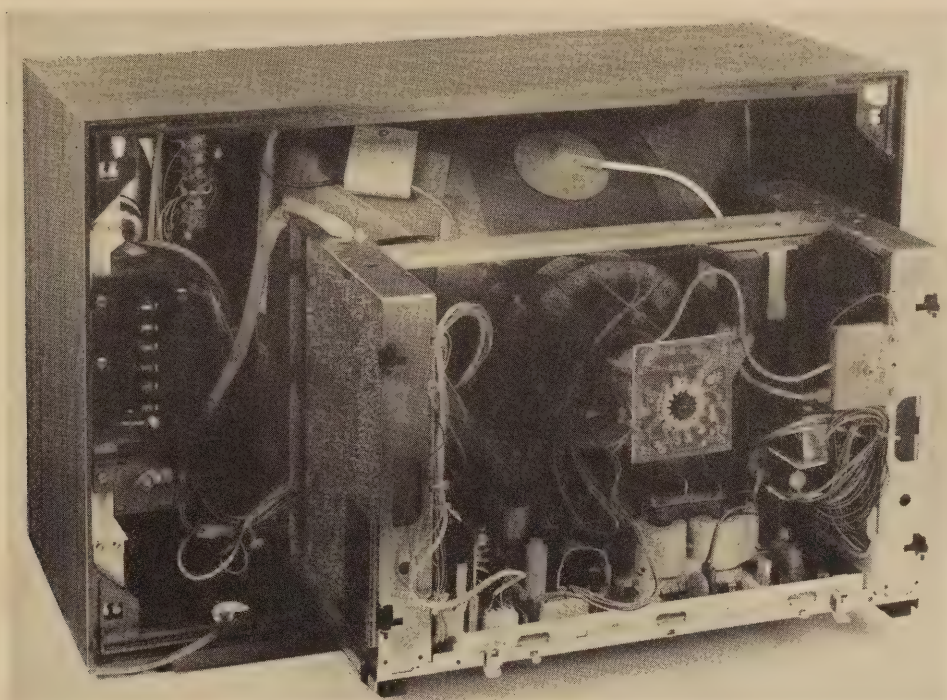


Fig. 7. Rear view of 1975 20 in colour receiver using new PIL stripe tube. *Courtesy: T.C.E. Ltd.*

Reliability

Despite the continuous study and application of cost reduction, over some ten years and increasingly over the past five years, television receiver engineers have also paid increasing attention to the subject of reliability. In use daily by the viewing public for an average of five hours, or 1,750 hours per year in the UK, any interruption by failure of the television receiver during a programme always causes annoyance—and calls for rapid repair.

The first colour receivers made in 1968–70 ran at an average of about five failures per year. Present-day receivers can be expected to require attention less than twice per year. A similar position applied to early monochrome receivers of dual-standard, valved make-up, which failed approximately four times per annum. A modern transistored receiver is unlikely, on average, to fail more than *once* per year.

As with most electronic equipment, the failure rate with time assumes the well-known bath-tub curve, i.e. a new production receiver can have a failure rate during the first 100 hours 'burn-in' period of three times the rate at 500 hours. In an effort not to disappoint new purchasers of equipment, many manufacturers undertake expensive 'soak testing' during the production test period of up to 24 hours. Most failures are due to batch problems with various parts brought in from outside suppliers, e.g. power transistors, i.c.s, tuners, hybrids, e.h.t. multiplier units, electrolytic capacitors, wound components and the like. Considerable vigilance in checking incoming supplies before use is necessary.

Production faults centre on the inevitable dry or badly soldered joints (which dip-soldered printed panels did

not improve), also poor contact in plug and socket cable connexions, etc.

In large television rental organizations, since service is their business, elaborate pre-production appraisal of sets is undertaken before general release and subsequently field reliability is carefully monitored.

Future Trends and Developments

Under this heading, brief reference is made to new developments which can be used with television receivers for picture reproduction.

Video Tape Equipment

Apart from the very costly professional 2 in (50 mm) video tape machines such as are used in BBC and ITV studios, in the past three years several recorder/players at prices under £500 have been marketed. These can be simply connected to a domestic television receiver for use as a picture monitor for recording off-air programmes or the playing of pre-recorded cassettes. Of these, the video cassette recorder available from Philips and in UK by Thorn, is by far the cheapest at prices of the order of £350–£500 according to detailed specification. These machines use a $\frac{1}{2}$ in width tape, in a special cassette, with semi-helical scan and up to 60 minutes playing time. Whilst the resolution in terms of bandwidth is limited to about 3 MHz, nevertheless, the picture quality, colour and monochrome, is sufficient for entertainment or training purposes. A full technical description can be found in reference 9.

Video Disks/Players

Another development, already demonstrated, is the use of pre-recorded disks for playing video plus audio

programmes for entertainment or training purposes. Unlike the video tape machines, individual recording is not possible with this conception, which is based on mass production of disks made from very costly masters. There are currently at least three contenders for this potential market, of which only the first has so far been launched:

- (i) Teldec: a development by Telefunken and Decca;
- (ii) RCA by the Radio Corporation of America, and (iii) Philips-MCA-Thomson-CSF separately developed by each company, but similar in concept.

Teldec uses a flimsy disk, air-supported, and relies on hill-dale recording to a pressure sensitive ceramic pick-up. Playing time limited to approximately 10 minutes per side.

RCA use a capacitance sensitive pick-up; tantalum strip-sapphire skid, running in a groove of constant depth. Capacitance changes result from troughs which vary in size/spacing formed *beneath* the groove, thus conveying recorded information. Playing time is 30 minutes.

Philips/MCA/Thomson-CSF use a minute laser generated light spot (1 micron dia.) producing reflexions off surface indentations and picked up by photo-cell. There is no mechanical contact with the record surface which has only a spiral of indentations. Two further light spots are used for track guidance feedback. Playing time is also 30 minutes.

All three systems have been demonstrated to give commercially acceptable television pictures but *Teldec* has the disadvantage of short playing time and flimsy disks. Both *RCA* and *Philips MCA* use hard polyvinyl disks as the basis of their records—plus further surface treatments.

In order to pack the required amount of video information into 12-in diameter disks, dimensions and tolerances involved are almost of molecular order! To illustrate the point: an ordinary l.p. audio record has 320 grooves per inch (12 per mm). The *Teldec* has 7000 per inch (275 per mm), *RCA* 5,555 per inch (218 per mm) and *Philips/MCA* 12,700 (500 per mm). *RCA* has fewer grooves because rotational speed is lower at 450 rev/min, i.e. 8 fields per rotation, whereas *Teldec* and *Philips* go for one picture frame—2 fields per rotation of 1,500 rev/min.

A snag with video disks is that international standardization is not possible with 625 and 525 systems to play into ordinary domestic television receivers. Players should cost about one-half the price of a video cassette recorder. As to the system eventually adopted, cost will undoubtedly be a major factor.

There seems little doubt that disks and tape machines will co-exist for some years with the latter mainly used for educational and commercial purposes, because of its record facility and its cheaper cost for a few copies and the former for domestic entertainment. Should the relative cost of the video cassette recorder be reduced and performance improve still further, then, as with audio, it might eventually fill both functions.

Teletext (Ceefax and Oracle)

One way of sending copies of documents, drawings, and other still material is to 'point' a television camera at

the item required and reproduce the required information directly on a receiver screen at the far end—assuming the bandwidth, say 3 MHz, and channel space is available. In the future, when wide-band cable television networks are generally available, such a service will become feasible. As an alternative, with some limitations as to information content, but displaying considerable ingenuity, during the years 1971–74, BBC and IBA engineers developed a system whereby the required information is transmitted over the air simultaneously with, but not interfering with, a television picture channel. Known as *Ceefax* and *Oracle* respectively, but increasingly referred to as *Teletext*, the encoded digital information is transmitted during the field blanking period.

As displayed on the 625-line television receiver there are 24 rows of 40 characters, i.e. 960 in total are available. Each character is formed of a 7×5 dot matrix. A complete row of characters occupies ten television lines per field. The character period is 1 μ s, each dot making up a character is 1/6 μ s. 240 lines per television field are used for data as simple graphics, the balance being space between rows of characters, etc. Up to 100 'pages' of information can be stored in the system.

The reader is referred to published papers for details of the system.^{7,8} Commercially produced decoders, using some large-scale i.c.s are currently becoming available at a cost of the order of £100.

Daily transmissions, on an experimental basis, are already available from BBC and IBA.

Cable Television

In pre-television days of the early 1930s, several companies were formed and ran successfully for many years, distributing sound broadcast programmes from local centres via cable, to many homes in various towns, particularly where off-air reception was poor. The signals were distributed at audio frequency generally over cable pairs direct to loudspeakers. With the coming of television and cheaper transistor radios, the sound relay systems began to run down and lose subscribers. In the 1950s these systems were then converted to television distribution—some companies retained the cable 'pairs' and used h.f. carriers for television signal distribution. Other companies changed over completely to coaxial cable v.h.f. distribution. The h.f. distribution companies claimed cheaper but special receivers (terminal units) omitting tuners, because all channels are transmitted on *common* frequencies on multi-pair cables. Selection of programme is by simple switching. V.h.f. coaxial companies use standard 'off-air' receivers relying on normal tuner channel selection from channels spaced over the 40 to 240 MHz spectrum.

Overall, on a cost basis, there is little to choose between the systems but, like railway gauges, there is a need for standardization. The v.h.f. coaxial system is more flexible in some respects for extension of services and is in majority use in countries other than UK.

In towns where television reception was poor the relay services, as they are known, provided successful service

of good signals to all homes. They chose receiving sites on hills at points of good signal level and relayed the signals over cable into the towns. Increasingly over the past five years, BBC and IBA, regardless of the existence of these services, have established more and more 'filling-in' satellite u.h.f. transmitters—often on the same hills as the receiving sites for cable systems! This regrettable situation has meant that more and more cable systems have become non-viable because at the same time, cable companies were not permitted to relay any additional services. Rather late in the day, the future of Cable Television is being reviewed as one of the terms of reference of the Annan Committee.

As to the future, *it is important to realize that the need for extension of 'cable' distribution facilities is not only dependent on an increase in television broadcast services as we understand them up to the present.*

By 'cable' distribution is implied, for the future, integrated networks making best use of complementary technologies such as cable, microwave links, optical fibres, waveguides and even satellites.

Technological development of broadcasting needs to be planned side-by-side with the development of other telecommunication services and requirements. Already we see the successful start of two-way communication by individuals participating in 'phone-in' and 'access' programmes.

Wide-band two-way cable links to all homes with central exchange switching can provide access, on demand, for subscribers to centralized information, minority programmes video-recorded, viewphone, viewdata, television doctor, hospital diagnosis and so on.

The possible extensions to these services are virtually limitless, but the channel space does not exist purely over the air. The subject is dealt with at some length in the NEC Working Party Report on Telecommunications and Electronics in Broadcasting of March 1975 to the Annan Committee, also the Post Office Report of December 1974, to the same body.

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Television Broadcasting—Engineering or Entertaining?

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The evolution of television broadcasting over the years is surveyed and the reasons for decisions on standards discussed. Television engineering today is increasingly the design of systems that no longer require engineering skills to operate large numbers of analogue controls.

One of the great, if too often overlooked, pioneers of radio—Henry Joseph Round—once said: ‘I have had the good fortune to live through a period of acceleration of human knowledge, the like of which may not be seen again, and the luck to be an observer standing fairly near the centre of this terrific activity . . . After a normal college career . . . I joined the Marconi people . . . my own professors were very disgusted and it was suggested by one of them, a great engineer, that I would do much better as an electricity station engineer, as electric lighting was the coming thing.’

Again, Professor J. D. McGee (who, as a member of Shoenberg’s research team, contributed so much to the early development of electronic television cameras) has recalled: ‘When I was a research student in the Cavendish Laboratory a group of us had visited Baird’s Studio—probably during 1930—for a demonstration of his television system. We had returned to Cambridge without much enthusiasm for this new development. It is true we were atomic physicists and so perhaps not inclined to give much thought to television. When eventually the time came for me to earn a living, jobs were very scarce. My supervisor, Sir James Chadwick, found one for me. It would be to work on television at EMI. His pessimistic *obiter dictum* was: “Well, McGee, you had better take this offer, since jobs are scarce. I don’t think this television business will ever come to much—but it will keep you going until we can get you a proper job.”’

These two quotations sum up the academic view of radio and television engineering over many years: a job not quite of the Engineering Establishment—a rather raffish way of earning a living, bordering on the wicked world of entertainment.

And yet, in practice, radio and television engineering has accomplished as much if not more than almost any

other of the modern engineering disciplines, not only within its own field but in providing the components and circuit techniques for virtually all of modern electronics and radar. It has occupied the attention of many inventive minds from Blumlein to Zworykin: it has created video recording and compatible colour in the United States; from Henri de France came the use of delay lines; from Holland came the Plumbicon, a decade in gestation; from Japan not only the present industrial marvels, but the Yagi antenna in the twenties; Germany pioneered v.h.f. television in the early thirties and PAL in the sixties. Switzerland has given television not only a meeting place but the Eidophor large screen colour display.

And consistently among the front-runners, the United Kingdom has won its place in engineering history—not just for John Logie Baird, the catalyst who made people take television seriously even if he himself, although a genius for making things work, could never concentrate long enough to solve the problem at hand before rushing on to the next. Baird may have contributed little of lasting value to television engineering but we must admire his flair and enthusiasm, and to the public he remains the inventor of television, demonstrated at Selfridge’s just 50 years ago.

Modern engineering training, it has been said, often seems to act against the acquiring of any deep interest in the way things developed; a mass of technical detail and mathematical expertise has to be learned or assimilated in a relatively short time; daily lives are concerned with the development of the new rather than re-examination of the past—even though much that is ‘new’ is foreshadowed in or may stem directly from a reappraisal of past ideas and aspirations. In electronics, ideas have frequently come many years before the materials and processes have been available to make practical implementation possible. Poulsen’s magnetophone languished for many years before the modern tape recorder was developed; Blumlein’s 1929 stereo disk records stayed on the shelves at Hayes for almost 30 years; elementary forms of transistor were uncovered in the cat’s-whisker days of the early ’twenties—but, even if the semiconductor phenomena had been understood, it is doubtful whether existing industrial processes could have produced material of the required purity.

Today, television is on the brink of further profound changes in the progressive adoption of digital techniques; techniques that were pioneered so many years ago by Samuel Morse and Alfred Vail or in the thirties by Alec

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Mr. Steele serves on numerous government, international, and learned society committees and he represents the IBA on the National Electronics Council.



Fig. 1. Despite the useful work of Baird and the other pioneers of low-definition 30-line systems, modern television broadcasting dates from the opening of the BBC studios and 45 MHz transmitting station at Alexandra Palace in north London. The first transmissions were for Radiolympia in August 1936 using alternately the Baird mechanical-electronic 240-line system and the all-electronic Marconi-EMI 405-line system. Regular transmissions began in November 1936 and the 405-line system chosen in February 1937.

Reeves whose pulse code modulation system, now the basis of so much current television research, was not implemented, even for speech transmission, until a decade or so after the idea was conceived. Engineering is often watering and tending the seeds of other people's ideas, and should not be thought any the less of for that reason.

Professor McGee has described the exceptional contribution to high-definition television made by the Marconi-EMI team under Sir Isaac Shoenberg in the relatively short period 1931 to 1936. He has pointed out that when the work began we had not even begun to understand the physics of photosensitive materials, with the technology still at the 'rule of thumb' stage; vacuum technology was just beginning to be adequate though glass-to-metal seals were very unreliable; electron optics had not even been formulated as a subject, nor had the physics of the solid state on which phosphors depend; secondary electron emission was recognized as a phenomenon, but very little was known about the details of the effect; radio-communication techniques were 'unbelievably primitive . . . amplifiers of reasonable bandwidth, scanning circuits, pulse circuits, even smoothed h.t. power supplies, radio transmitters with bandwidths of more than a few kHz with a v.h.f. carrier frequency, and so on, all had to be invented as we went along.'

The Selsdon Television Advisory Committee after seeing the 180-line experimental system developed by the Telefunken and Lorentz companies in Berlin, recommended for the U.K. a standard of 'at least 240-lines' and regular public high-definition television was launched by the BBC in 1936 alternately using the Baird mechanical/electronic 240-line system and the Marconi-EMI 405-line fully electronic system. Within three

months a choice was made in favour of the electronic system.

The decision by Shoenberg to opt for 405-lines rather than 240 has been called the biggest and most courageous in his career. The figure of 405 came about in the following manner. At that time—and for many years subsequently—it was the practice to 'divide down' precisely the basic line frequency to provide the field frequency and to lock the chain to the mains-supply frequency.

Blumlein and his colleagues had developed a 243-line system since this allowed a series of divide-by-three multivibrators to be used ($3 \times 3 \times 3 \times 3 \times 3 = 243$) but were anxious to try a higher definition system. The simplest way of doing this was to convert one of the multivibrators to divide by 5. The system was now $3 \times 3 \times 3 \times 3 \times 5$ or 405 lines. That was how the figure '405' came into television history: it has already been with us 40 years and seems destined to linger on a few years yet. It could so easily have been '243'.

Initially then, '405' was not the choice of an official committee, but *ab initio* of Blumlein and Shoenberg. When almost a decade later this standard was endorsed by the Hankey committee it was by then the *wrong* decision, overtaken by developing technology.

This committee—'The Television Committee 1943'—was set up during the war under the chairmanship of Lord Hankey and included such distinguished scientists and engineers as Sir Stanley Angwin, Sir Edward Appleton, Sir Noel Ashbridge and Professor J. D. Cockcroft. It succeeded in being, at the same time, too

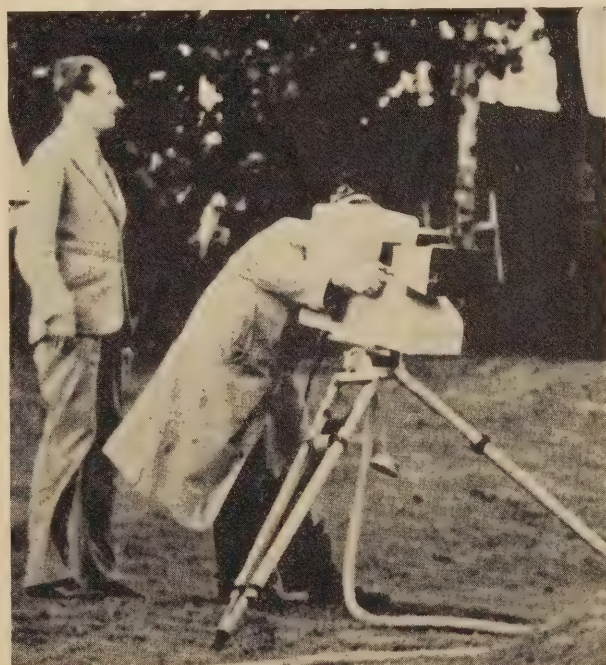


Fig. 2. The early 'outside broadcasts' were mostly from the grounds of Alexandra Palace, including race meetings and golf demonstrations, but a 'travelling control room' was soon in use housing three cameras and mixing facilities for six microphones.

ambitious and yet too pedestrian. For the committee clearly foresaw the need for a higher definition system of which British television could be proud and that developing technology made this possible; one of its central recommendations was that work should be started vigorously in developing a 1000-line (or thereabouts) system suitable for cinema presentation and 'incorporating colour and stereoscopic effects'.

They even 'gave much thought to various considerations for and against the adoption of a 525-line standard' (as by then in use in the United States) and noted the advantages in the 'interests of international standardization'. They appreciated that it would be relatively simple to effect a change of standards while there were still only a few thousand of the 20,000 pre-war receivers in working order. But they believed that 405-lines and 1000-lines could exist together for a time—appealing to different users.

It is part of the legend that EMI offered to stage a demonstration of a system on 605-lines which might so easily have become a European standard. But the committee is said to have declined the invitation. While the exact details of the events of 1945 appear to have been lost in the mists of time, there is little doubt that EMI and some others urged strongly that the time was ripe for a change upwards in line standards—and had a 605-line system in the laboratories; later they and others developed a 1000-line system. But the Hankey committee, with the BBC anxious to resume television, made their classic error and the opportunity was lost. To the Hankey committee also belongs the concept of a duplicated service on different line standards. Born in 1945, it is still alive today.

So the recommendation was made and accepted—and 20 years later was to present British television with all the problems of duplication and u.h.f. not as an addition, but making the whole system run a lot faster just to stay in the same place. That engineering has made a success of the u.h.f. network and 625-line duplication should not blind us to all the problems and costs to broadcasters and viewers that stemmed from these two decisions: in 1945 to stay with 405, and then in the 1960s to change not to over-1000 but to 625-lines. It is a lesson to us all of the importance of committees making the right decision at the right time.

Fortunately, in 1966–67, a standards decision was made that *has* proved to be the right one for the United Kingdom: the long and often bitterly fought political/economic/engineering controversy over the choice of a colour-encoding system. With so many factors involved the decision was not an easy one—and the view sometimes expressed at the time—that it should only be necessary to lock a few engineers together in a room until they made up their mind—was a caricature of the true situation: engineers were as divided and as committed as the others. The three principal rival systems all had potential advantages and disadvantages. SECAM was a particularly rugged system and introduced the use of delay lines (but at that time these were highly specialized, expensive components which it might or might not be possible to mass-produce). NTSC was tested and tried

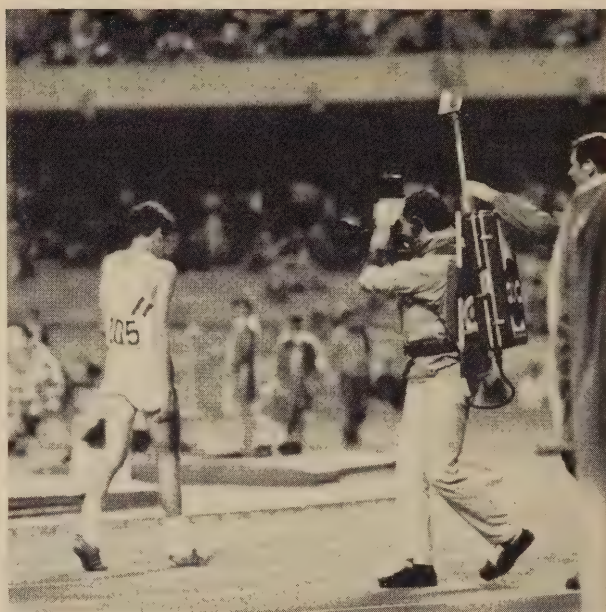


Fig. 3. One of the trends in television is towards mobility and electronic news gathering. A shoulder-carried camera and back-pack video-tape recorder at the Mexico Olympics in 1968.

but required distribution networks of impeccable performance: even more decisive was that it had been developed before video tape recording and presented the problem of linear phase errors to the machines of that era. Walter Bruch has said of PAL that 'its father was NTSC, its mother SECAM' but at the time it was uncertain how the infant would turn out. Now 12-years old we can be satisfied that he combines the best qualities of the Old and the New World, Yankee get-up-and-go, Gallic colour fidelity and a sturdy Teutonic character helped along by some suggestions from our own shores—and the invaluable Dutch Plumbicon pick-up tube that presented so many problems in development but finally arrived just in time to make possible excellent colour cameras little larger than we had grown used to for black-and-white.

Indeed the 4½-in image orthicon—first produced by EEEV in the UK—had been virtually the end of the long line of development of monochrome cameras that had started with the independent work of Zworykin in the United States and the EMI team at Hayes: a camera capable of providing brilliant black-and-white pictures, during the period which saw the gradual emergence of the zoom rather than the turret lens.

Studio engineering also changed profoundly during the late fifties and early sixties—a change in which a young Independent Television played a very full part with the introduction of purpose-built studio centres, more ergonomic control suites and the gradual separation of the technical areas away from the studio floor. A new era also dawned when Associated-Rediffusion in 1958 brought over the first Ampex video-tape recorder to reach the United Kingdom. Until then most television productions had been 'live' and though this made the adrenalin flow, it ruled out the elaborate productions to

which we have now become accustomed. The successful development of a compatible colour system and video tape recording must be ranked as the two peaks of post-war television engineering and both occurred in the mid-fifties in the United States.

In retrospect it may later be possible to claim a third major breakthrough—the development in this country of the Oracle and Ceefax Teletext systems with their entirely new approach to information services, free from the constraints of time and yet making no fresh demands on the electromagnetic spectrum.

If television had developed on rational lines with a common international standard there would have been no requirement for standards conversion; without a common standard, however, conversion equipment is essential. Much time and effort has gone into resolving this problem—a major advance was made by the BBC with the electronic analogue machines of the sixties. In the IBA we now like to feel that with DICE (digital inter-continental conversion equipment) we have reached the definitive stage of resolving this problem with two-way conversion virtually without picture impairment or the need for constant alignment.

International television, of course, has come a long way since the first cross-channel relays in the early 'fifties. The performance of Eurovision links we now take for granted: the synchronous satellites bring to us—albeit at considerable expense—news and sporting events from all continents, though these transoceanic links have been



Fig. 5. The first live relays of television across the Atlantic became possible in 1962 with the launching of NASA's *Telstar* satellite, in readiness for which the Post Office built its first satellite ground station at Goonhilly Downs. The original dish was 85 ft in diameter and was later modified for use with the synchronous satellites that have enabled television coverage to become worldwide.



Fig. 4. The next decades are likely to see increasing use of digital techniques. The first major digital-video equipment to enter operational service was the IBA's DICE standards converter, installed at ITN early in 1973.

the creation of telecommunications rather than television engineers. Again, a future advance will almost certainly be digitalization but for the viewer the difference will not be great.

What then is the present engineering function in television? In our submission to the Annan Committee on the future of broadcasting, the IBA has suggested that this might be defined as follows:

'For several decades there has been progressive development of broadcasting equipment and techniques that make it far less necessary for an engineer to stand as a middleman between director and viewer. Initially television, it has been said, was the "toy" of the engineers who dominated the scene. They determined what could and could not be in the studios; who could or could not receive the programmes; how close to the camera the actors must stand and in what temperature; how much make-up they needed; how far outside the confines of the studios the camera could venture. The daily operational role of the engineers has now diminished. The engineers have provided the programme production staff with equipment which they can, in effect, virtually operate themselves. Within the studio complexes, the technical areas have increasingly been concentrated away from the studio floor, with versatile switching systems to allow the recording and playback machines to be assigned to different studios and to be operated remotely.

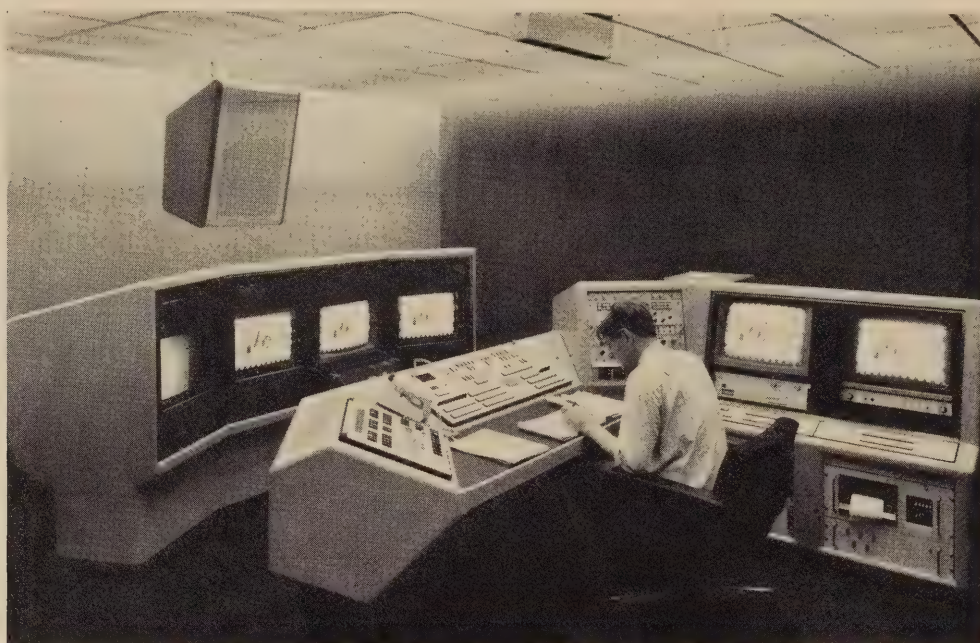


Fig. 6. With the conversion to 625-line colour operation on u.h.f. the opportunity was taken to build the new transmitter networks for unattended operation. One of the IBA's 14 colour control rooms from which the entire network is controlled but which are to be gradually reduced in number until a network of over 400 transmitters will be run from only four regional operations centres.

'Transmitters and camera channels are no longer attended by a clutch of technicians, caring for their complex racks of electronics, one technician to every ten knobs or so. Today it is in the planning of the systems and networks, the development of entirely new facilities and the maintenance of technical quality that is to be found the true role of the engineer; simplifying operations, making them more economical, more tolerant and to more consistent standards of quality.

'The engineer therefore still has an important, if less spectacular, part to play in any organization concerned with broadcasting. It is the engineer who recognizes the limitations of existing equipment, the constraints of bandwidth, radio-wave propagation and physics; who is likely to see most clearly and quickly the opportunities for television in new developments in other branches of science; who conceives and provides the new facilities with which the programme makers can exercise their imagination; who seeks to provide video tape recording with the traditional editing flexibility of film; who recognizes that television will increasingly be based on digital rather than analogue techniques; who can foresee the technical and operational advantages and problems in direct broadcasting from satellites; who, if necessary, still restrains the enthusiasm of the programme maker with the cooler judgements of science; who, in brief, uses his flair and imagination and knowledge and grasp of engineering-economics in the service of broadcasting—just as the programme makers use their flair and imagination, and knowledge and grasp of production-economics.'

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Broadcasting and Receivers

Professor W. GOSLING, B.Sc., C.Eng., F.I.E.R.E.

Developments in broadcast and communications receiver design are shown to have been governed by the need to conserve the use of the frequency spectrum. Future trends in m.f. broadcasting may be based on a type of s.s.b. while stereo broadcasting in this band is a possibility. The use of microwaves and satellites will present challenges in engineering these techniques to meet growing spectrum congestion.

How Things Began

For many of the present generation of senior electronic engineers, the starting point, in boyhood, of their professional commitment was an interest in building radio receivers. It usually began with a desire to build receivers for m.f. ('medium wave') broadcast reception, and the first sign of the condition would usually be a flirtation with crystal detectors. The more serious rapidly progressed to simple valve receivers—usually a reacting leaky-grid triode detector followed by a single a.f. amplifier—and many a highly placed engineer today will become a little wistful at the thought of a KT2 or a PM1HL.

Often interest was sustained by a move to h.f. ('short-wave'), with the aid of such exotica as the D210SW. An important milestone was the day when enough pocket money was scratched together to buy a pair of i.f. transformers (the price was remarkably constant at 15 shillings for a very long time) and the world of the superhet consequently opened up. Teaching the local oscillator to track in the total absence of test instruments sorted the men from the boys, indeed the latter frequently grew into the former in the process. The construction of a transmitter, licensed radio amateur status, and membership of the Radio Society of Great Britain often followed (in variable order).

The more advanced amateur, and certainly those who studied radio engineering professionally (often as a small and apparently threatened component within an electrical engineering or physics degree course) concentrated their attention on radio receiver design in a way that present-day electronics undergraduates would find rather startling. In my own undergraduate days the only non-radio electronic circuit (apart from power supplies) that I was taught about was the binary scaler, and since my teacher was Dr. C. E. Wynn-Williams (who invented it) the inclusion was perhaps not unreasonable. We were taught relay logic, but since our mathe-

maticians were flushed with a sense of triumph at having just built a Von Neumann computer (as they were called) from PO-type relays, this too was not entirely incomprehensible. Even so, I suspect that I had a rather 'fast' electronics education for those immediate post-war days.

Returning to radio receivers, theoretical treatments at that time emphasized the importance of selectivity and sensitivity. Selectivity, we were told, was the ability to reject adjacent channel signals (although I am not at all sure that was the particular expression used) and was determined by, predominantly, the i.f. filters. Sensitivity was determined by the noise factor of the input stage of the receiver, which was a good reason for using an r.f. stage in front of the mixer—preferably a grounded-grid triode rather than a pentode because of the absence of partition noise. Non-linearities in either r.f. or i.f. amplifiers were not considered (except for limiting i.f. amplifiers in f.m. receivers—a very advanced topic) and the only spurious responses of the receiver taken into account were second-channel (image) response, which was suppressed by the r.f. filter, and i.f. breakthrough. That was avoided by an i.f. trap in the aerial circuit. In short, we were taught to design receivers for a radio frequency spectrum in which there were very few transmissions.

In some bands this was all too true, and brings to mind the tiresome hours spent with a primitive v.h.f. receiver listening to white noise on the old amateur 56 MHz allocation, whilst searching up and down the band diligently for some—any—transmission. Even a quarter of a century ago, however, the h.f. band was filling up, and the 7 MHz band on Sunday mornings was already notorious. M.f. could be difficult in winter after dark, but my 'hi-fi' radio tuner in the late 'forties still consisted of an aperiodic r.f. amplifier (VR65A), a critically-coupled pair of resonant circuits as the only source of selectivity, and a cathode follower a.m. demodulator (6J5). (The 'back end' was thought a little eccentric; a 6SJ7 audio amplifier followed by push-pull 6F6's.)

It was at this time that the police were deciding whether to proceed with an m.f. radio system, as planned before the War, or go for v.h.f. John Brinkley at the Home Office made the critical advance¹ which gave v.h.f. mobile radio such a success in Public Service use.

At about the same time the BBC was competitively evaluating f.m. and high quality a.m. for the proposed v.h.f. broadcasting service, with test transmissions from

Professor William Gosling, B.Sc. (Fellow 1968) who graduated in physics from Imperial College in 1953, was appointed to the newly-founded Chair of Electronic Engineering at the University of Bath in January 1974. He was previously at the University College of Swansea for some 16 years and had been Professor of Electrical Engineering and Head of the Department of Electronic and Electrical Engineering since 1966. He is Chairman of the Professional Activities Committee and was elected a member of the Council in 1970, serving as a Vice-President from 1972 to 1975.

Wrotham. If you plan on the assumption that bandwidth costs nothing, f.m. is bound always to win, as it did on this occasion.

'The times, they are a'changing'

So many exciting things have happened in electronics since World War II that the radio receiver long ago lost its position of primacy in the undergraduate curriculum. Elbowed aside by microwaves, digital developments and control engineering, it has become almost a specialist study, to the point where some electronics graduates today have received no formal instruction at all on any aspect of radio hardware.

Time, however, has not stood still, and the character of the technical problems of radio, and with it the scientific understanding of how solutions to them can best be found, has now changed profoundly. The key to understanding this is to realize that in radio communication the problems are those of growth.

Many indicators of economic activity have shown exponential growth over our lifetimes. Power consumption, for example, has shown a characteristic doubling every ten years or so, and line telecommunications also has shown about a seven-years doubling time. Transatlantic circuits have doubled in number about every four and a half years, and in the UK land mobile radio showed a similarly rapid rate of growth, increasing ten-fold in the number of users between 1960 and 1970. Broadcasting has experienced the development of competing television systems and more recently the introduction of local broadcasting. The number of broadcast sound receivers in use has increased dramatically, in parallel with the progressive reduction in their real cost.

It is true that many of these indices are no longer growing, consequent upon the world economic recession stemming from the oil crisis of 1973. As yet it is too early to be sure whether this is, as seems most likely, a temporary perturbation, to be followed by renewed exponential growth, or whether, as some believe, in certain areas the transition towards the steady state, zero growth, economy which must necessarily characterize the 21st century in the developed world, has already begun. Even if this latter view were the correct one, not all the growth indices would decelerate at the same time, and it is therefore pertinent to ask what, in fact, are the limits to growth in radio engineering.

Evidently neither energy nor materials limitations are relevant here. Even quite a large radio transmitter uses no more energy than would be required to heat two or three private houses in winter, and in fact almost all non-broadcasting radio applications involve power levels comparable with or less than that of an electric light. As to materials, the principal tool of the contemporary electronic engineer is the silicon microcircuit. It is thus from one of the Earth's most plentiful elements that our equipments are built—almost literally from the sands of the sea. There are some technologies which depend on scientific understanding very greatly and material and energy resources very little. Microelectronics is one of these. Thus neither materials exhaustion nor a develop-

ing energy cost increase would have very much impact on the rate of growth of radio.

The resource upon which radio depends, and which is ultimately capable of limiting the range of uses to which radio will be applied, is the finite electromagnetic spectrum. All radio transmissions used for communications are contained in the electromagnetic spectrum, which begins at about 10 kHz. The upper limit is set by water and atmospheric absorption, so that the volume of open transmission radio falls sharply beyond 10 GHz and is virtually extinguished beyond 17 GHz (Fig. 1). This implies that all radio communication will be permanently linked to this available spectrum: no more can ever be made available. The result is bound to be growing congestion on the radio bands. Some are already very bad in this respect, others as yet almost

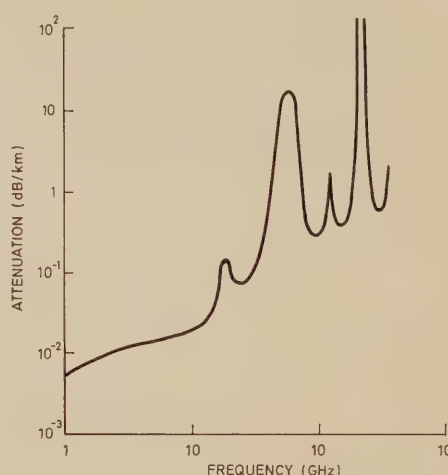


Fig. 1. Variation of atmospheric attenuation of radio waves with frequency.

unaffected. If social demands continue to develop, however, at all frequencies congestion is bound to be the ultimate restraining factor. Because of the rapid rates of growth of use it is possible to move from a near-empty band to gross spectrum congestion in only a few years. For example, if the amount of spectrum used for mobile radio could be doubled overnight, such as by re-allocation of some bands, the present congestion would be back again in under five years, at present development rates.

The impact on broadcasting and radio receiver technology is profound: the sensitivity of a receiver today is determined by its spurious responses in congested bands, only in a very few situations by its noise level.

The Impact of Spectrum Congestion on Broadcasting

Sound broadcasting ought perhaps to be entirely v.h.f., but m.f. stubbornly refuses to die. M.f. receivers will perhaps always be cheaper than those for v.h.f., and there are fewer reception 'black spots' and less difficulty with car radio in the m.f. case (although to be fair, the car radio problem has been much exaggerated). With

the development of EEC institutions, m.f. radio has the advantage of offering Europe-wide broadcasting, which at present v.h.f. cannot do, although satellite broadcasting could change this. Thus m.f. will not die in the foreseeable future.

Even so, reception can be very poor, particularly after dark and in winter, when sky-wave propagation leads to severe co-channel interference and multi-path propagation impairments. The spectrum is not being optimally used: it is a commonplace that if lower transmitter powers would be accepted, the amount of mutual interference would be so much reduced that a considerable improvement in service will result. However, this would require agreement and joint action by all broadcasters, which it has not so far proved possible to achieve. In the political climate which prevails perhaps it will never be achieved. Democratic states have difficulty in conveying to the general public, and even to M.P.s, the subtleties of complex technical arguments, and indeed it may well be that popular scepticism about the benefits to be obtained from international co-operation is realistic, when one considers the extent to which the success of any such move could be undermined by just one non-cooperating nation.

In the meantime detailed improvements,² aimed at improving the utilization of spectrum with existing technical standards continues. The coming of v.h.f. broadcasting has meant that the role of m.f. has been able to change also. Now that it is no longer the only medium available certain aspects of the performance can be degraded provided that no noticeable deterioration in performance on the simpler transistor portable or car radios occurs: a 'hi-fi' service is no longer obligatory. The curious m.f. broadcasting practice of years gone by, in which transmitters on carriers spaced at 9 kHz intervals were allowed to radiate spectra extending to ± 10 kHz, is passing and a real attempt to restrict spectra to ± 4.5 kHz is now made.

A topic of much greater controversiality is the role (if any) of single-sideband in future m.f. broadcasting. As spectrum congestion gets more severe the attractions of s.s.b. in all frequency bands and for all services become more enticing. In h.f. professional radio communications it already reigns supreme. In principle it could offer a reduction of 2 : 1 in bandwidth occupied relative to a.m., although in practice the saving may not be so large. Inevitably it has its proponents for m.f. broadcasting, but the difficulty is the mass production of satisfactory s.s.b. receivers. A good deal of attention has been given to the problem³ but little has yet happened to indicate a definitive solution. The introduction of quartz crystal watches may improve the mass production economics of crystals to the point where a crystal-controlled fully synthesized m.f. broadcast receiver is feasible, but at present the prospect seems remote. Even then a very difficult a.g.c. problem will remain to be solved.

Attempts to produce systems based on s.s.b. with non-suppressed carriers, which would obviously help the a.g.c. problem, and could exploit receivers phase-locked to carrier to overcome the frequency stability difficulty,

do not seem very attractive. The whole point of the s.s.b. exercise is to reduce channel spacings. If these were reduced to, say, 5 kHz but carriers were not suppressed the heterodyne whistles resulting would be hard to live with. Indeed carrier suppression or diminution might well effect a very worthwhile improvement of the audible effect in m.f. broadcasting even if d.s.b. were retained, but here again at a significant cost in receiver complexity. On the whole the independent observer is likely to agree, for the moment, with the view, widely held and apparently viewed sympathetically by the BBC, that the time for m.f. s.s.b. broadcasting is not yet. Obviously a major advance in receiver technology, such as microelectronics could well provide, might radically alter the situation. Interest in compatible s.s.b., which can be demodulated with an envelope detector,⁴ seems at a very low ebb at the present time, if only because it is likely that only very modest gains in spectrum utilization would result from its adoption.

Quite another area of development for m.f. is into stereo broadcasting. It was Kahn⁵ who proposed such a system and demonstrated successful stereo m.f. transmissions from the station at Tijuana, Mexico. The basis of the method is the transmission of one of the stereo channels on the upper sideband and the other on the lower of a d.s.b. transmission. Thus for stereo it is received as an i.s.b. signal, and a simple envelope detector a.m. receiver still receives a perfectly satisfactory monaural signal. Both transmitters and receivers are cheap and simple—almost absurdly so by comparison with v.h.f.-f.m. stereo radio—and very acceptable results are obtained.

Many broadcasting engineers would argue that stereo is out of place on m.f., which can only provide a second class service at best. However against this it is argued that stereo gives a greater improvement of acceptability in the received signal than any other change (such as improvement in frequency response or better signal/noise ratio) and can do so at no penalty at all in bandwidth occupancy, as compared with a.m. A stereo m.f. receiver also helps with the adjacent channel interference problem, since the unwanted sounds often appear to come very much from one or other edge of the auditory field and hence are more easily ignored. On the other hand, under sky-wave propagation conditions, with selective fading, this type of stereo gives very erratic results.

Even so, m.f. broadcasting is designed to avoid sky-wave propagation conditions, so far as possible, and m.f. stereo does, therefore, hold out promise. Significantly, over the last two years new patents have been filed in this area by major US companies.

Like all other receivers for the era of spectrum congestion, the modern m.f. broadcast receiver will have to improve its spurious response performance. The single bipolar transistor mixer, universal as a front end until the present time, must be progressively eclipsed in favour of designs with lower spurious responses. The 'long tail pair' mixer is a lively candidate, but even higher performance may be necessary. Microcircuit receivers permit quite complex configurations, within the limitations of available semiconductor processes.

V.H.F. Broadcasting

The f.m. system of modulation is now probably too firmly entrenched at v.h.f. to be dislodged, although it occupies five times as much spectrum as a high quality a.m. system would have done (Fig. 2). The phenomenal complexity of compatible f.m. stereo receivers (as compared with compatible a.m. stereo) is no longer the problem it might once have been, thanks to micro-electronic signal processing circuits. The future of v.h.f. broadcasting is probably thus rather orderly development along present lines, although with ever-increasing spectrum congestion receiver specifications, and in particular front ends, will have to continue to improve.

Happily, in the public mind an association has been made between v.h.f., stereo and high fidelity reception. This has made it possible to establish a higher cost v.h.f.-f.m. domestic equipment market than in the m.f. case. Equipment to semi-professional standards (and not all of it of Scandinavian origin) has helped to establish a point of reference at the upper end of the market. Although the volume of equipment of this quality sold is very small, it provides a technical challenge which lower-cost producers strive to meet—in some cases successfully!

V.h.f.-f.m. stereo radio tuners are able to provide a high quality stereo sound source and will thus probably stimulate the stereo cassette equipment market. Now that the Dolby noise reduction system is becoming accepted as an industry standard for compact cassettes, resulting in an audio performance (with chromium dioxide tape) fully competitive with vinyl disks but having an enormous advantage in robustness and longevity, it may be that the disk will undergo a slow eclipse in favour of magnetic recording.

Mention of the Dolby noise reduction system introduces the question of adopting this technique on f.m. broadcasting. This has already begun in the USA on an experimental basis. Since the growth of the Dolby recorder market is likely to lead to a fall in the cost of the relevant hardware once really large-scale production begins, the probability is a very real one, although the large investment in non-Dolby high-quality f.m. equipment by the public already must act as a brake on moves to change the system.

Experiments on four-channel broadcasting have been conducted, but there is a considerable question mark over the acceptability of quadrophonic systems. If, as seems at least possible, it remains very much the enthusiasm of a numerically negligible group of listeners, it is unlikely that broadcasting authorities will feel justified in introducing it. Evidence of much wider acceptance of four-channel audio recording equipment would be encouraging here, but is not, as yet, forthcoming.

Microwaves and Satellites

Interest in microwave broadcasting (specifically in the 2.5 GHz band) continues, stimulated by the belief that spectrum for new applications, such as educational broadcasting, may not be available at lower frequencies.

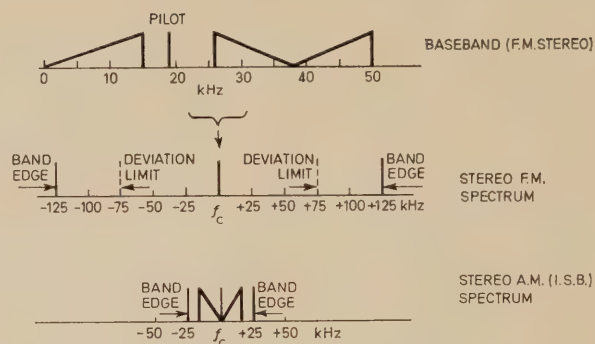


Fig. 2. Spectrum comparison: high quality stereo broadcasting systems in f.m. and a.m. form.

Actually the microwave bands are also now becoming very congested and the time for a development of this kind may already have passed. Certainly what is required, and will perhaps be supplied by the World Administrative Radio Conference in 1979, is a systematic view of the needs of all spectrum users. Realistic economic criteria will be needed—it will be necessary to ask what is the relative cost of an alternative to the proposed new spectrum use. In some cases, such as broadcasting, the cost of the alternative (e.g. cable distribution) is perhaps not inconceivably high, whereas for, say, land mobile and aircraft radio the cost is phenomenal.

Satellite broadcasting, probably in the microwave bands, has been the subject of much debate. Although earlier satellites had rather low power available, and hence could not be used for broadcasting direct to the domestic receiver, the projected development of the Space Shuttle will make it economic to assemble relatively large power sources (much extended solar generators or, less probably, nuclear reactors) in orbit. However, even then the future of satellite broadcasting is problematic. Only geostationary satellites can be used and these are about 37 000 km from the Earth. As a result (Fig. 3), with realistic aerial structures coverage areas of less than about 1600 km diameter are unattractive. There are few areas in the world where a common linguistic and political entity covers so large an area. Improvements in satellite and aerial technology may change this situation for the future, but if so, satellite

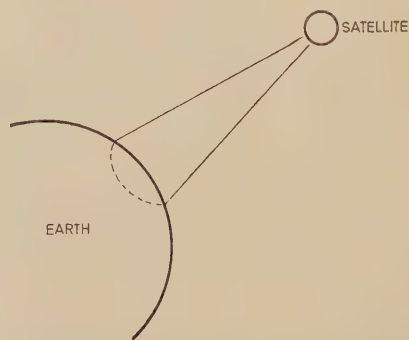


Fig. 3. A geostationary satellite must necessarily cover a large area even with a narrow beam aerial, because of its distant orbit

broadcasting will probably only make a contribution towards the end of this century.

Conclusions

Broadcasting and receiver design are both likely to respond primarily to the impact of growing spectrum congestion over the next decade or two. In the case of receivers, sensitivity is determined today more by spurious responses than by noise level in the receiver front end for most bands, and it may be predicted that front ends with a low spurious response level will be used more and more in future. New circuit innovations compatible with low cost monolithic integration are urgently required.

Because of the large investment in existing domestic equipment, broadcasting must necessarily adopt fairly conservative policies, but continued improvement of m.f. and v.h.f. services along present lines may be looked to, with perhaps an outside chance of the introduction of true s.s.b. at m.f. if the serious technical problems can be overcome at economic cost.

The radio receiver is the electronic equipment which everybody uses. No electronic engineering artefact is more commonplace or numerous. It has changed our world and its impact is not yet by any means at an end.

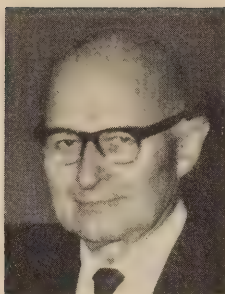
Problems of spectrum congestion are not grounds for pessimism, rather they must be seen as the great challenge of the last quarter of the 20th century, so far as radio engineers are concerned.

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Radio Navigation Aids: A personal view

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The author recalls some milestones in the development of one of the principal hyperbolic navigational aids, the Decca Navigator. The origins of two other aids, Loran C and Omega are touched on briefly and mention is made of the future use of navigational satellites.

This is a personal view of the highlights of Radio Navigation Aids rather than a formal technical description of them. It is hoped, however, that it will not only be interesting but that some of the technical problems mentioned will intrigue the serious engineer.

Obviously the main highlight for me is the Decca Navigator, as I have been so intimately connected with its development, manufacture and implementation. The inventor, William J. O'Brien, described a method of position fixing by comparing the phase of different, but related, low frequency waves after they had been converted to a common frequency.¹ He sent it to me the day war was declared, saying that it should help in the fight against Hitler. I made up a proposal and sent it to the Air Ministry but their scientists said it wouldn't work. Later we learned that the Gee system was being developed for the RAF. Gee is also a hyperbolic system with a station configuration similar to that of Decca, but instead of comparing the phases of continuous waves in the l.f. band it measures time difference by comparing the arrival-time of pulsed v.h.f. signals.

I next submitted our proposal to the Admiralty and, after several meetings, a decision was made to try it. We were given two months to produce equipment for a trial which took place on schedule and everything worked, much to the surprise of the Government representatives who were on board the demonstration vessel. Many subsequent trials took place during which most aspects of performance including 'night effect' were evaluated. The final test was a full operational trial off Wick, Scotland, with several ships fitted to prove that all receivers showed the same readings at a number of positions accurately defined by sextant. In retrospect, one wonders how many inferior nav aids would have been shown up and the millions spent on them saved, by such a practical test!

Mr. Harvey Schwarz (Fellow 1953) first became associated with the Decca Company in the 'thirties when in England on behalf of an American company which was acquired by the Decca Record Company. During the war he directed the development and application of the Decca Navigator system and in 1950 became Managing Director of the Decca Navigator Company. He retired in 1970 and now is acting as consultant to several organizations. Mr Schwarz was President of the Institution in 1970-71. He was appointed an Honorary C.B.E. in 1971.

This trial took place in February 1944 and was completely successful. During the first week in March we were asked to provide 27 receivers and new drive and synchronizing equipment for a master and two slave transmitting stations by the middle of May. By some miracle these were produced and the system was used by the minesweepers and leading landing-craft of the British Navy on D-Day. We were told that it played a vital role as the weather was atrocious and dead reckoning was way out. All of the equipment worked during the critical period and in the following ten days the only faults that occurred were on two of the receivers. There were no breaks in transmission and only 3 minutes had been allowed on the air prior to this operation. Today, station equipment is in triplicate with automatic switching and stand-by battery power supplies—then, not one component was even duplicated!

After the war a charter was obtained from the Labour Government for the private operation of Decca Navigator transmitting stations and the renting of receivers to ships, provided that we demonstrated the performance and reliability to the Ministry of Transport. Observers were put on board a number of designated merchant ships which were fitted with receivers. Within the first hours of operation the crews were enthusiastic but it of course took months before the night-time range of 240 nautical miles from the master station could be approved. Today, over 21,000 ships use the system and there are 40 chains, nearly all with 4 transmitters. The chains in the UK and Denmark are owned and operated by the Decca Company—a unique example of a navigational service provided by private enterprise.

The original receivers were of the integrating type only—the user had to set the meters before leaving port and keep the receiver on continuously. This called for very high reliability, and that is why so much effort was put into the design of the transmitting stations to ensure no breaks in transmission. Unintentional interruptions were measured in seconds per year. Even members of the American Government, who consistently fought against the standardization of the system, were very complimentary during the New York black-out when there were no breaks in Decca transmissions, whereas practically every other navigational aid was off the air.

The next highlight was the development of lane identification, a 'built-in' means of resolving the cycle ambiguity in the phase comparison. The ambiguous

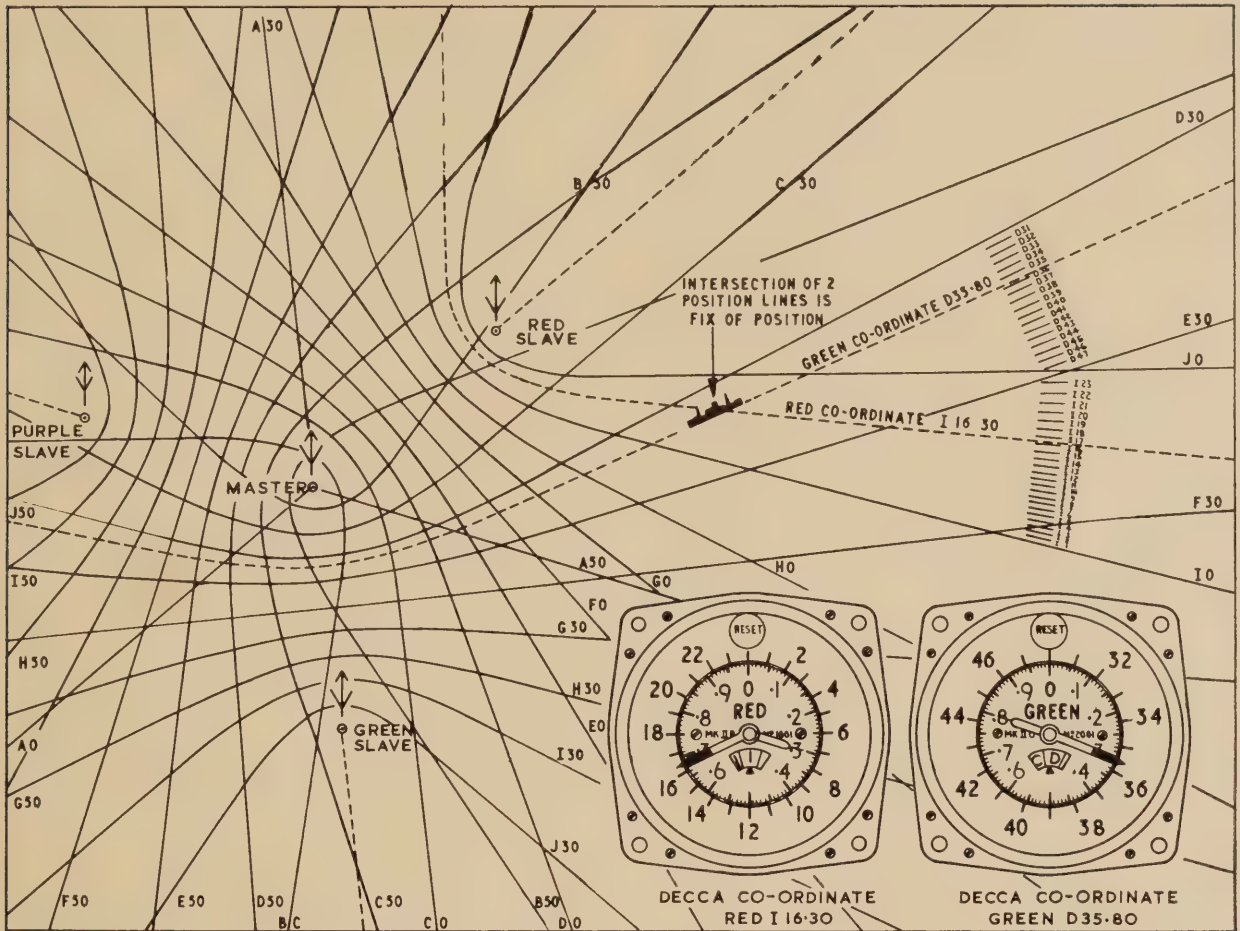


Fig. 1. The Decca lattice, Decometer readings and fix.

lanes are, on the average for the three patterns, about a $\frac{1}{4}$ of a mile wide on the baseline and lane identification entailed superimposing a coarse pattern having lanes about 6 miles wide, enabling the user to set in the correct lane numbers without having to know his position beforehand to better than ± 3 miles. The tolerance is several times wider in the outer part of the coverage where the lanes expand. This was done by periodically regrouping the chain transmissions in pairs from each station so that each provided a beat note of the same low frequency (about 14 kHz). Comparing the phase of the beat notes from the master and slave station gave the coarse pattern reading on the lane identification meter which was calibrated in the fine lane units. This was the first of a series of 'tricks' that the original choice of harmonic frequency relationships (master $6f$, slaves $5f$, $8f$ and $9f$) made possible. The beat frequency, of course, was $1f$. (Fig. 1.)

A subsequent trick proved to be a profoundly significant development of the system and it started with a conversation in an aircraft. In order to get maximum coverage from the French Decca chain (one chain was all the French Government said it could afford) the master-slave distances had to be stretched to about 100 miles. This resulted in excellent performance by daytime but the range of lane identification at night was

too limited. Returning to London from Paris after a rather stormy meeting I said to O'Brien 'Surely lane ident errors due to skywave could be significantly reduced if we could derive f by sending all four frequencies from each station during lane identification instead of just two'. He thought a bit and then said 'Yes, if we could do that it should enable us to handle about twice as much skywave but it will surely be too complicated both for the transmitters and receivers'. My reply, as usual, was 'You can do it', and so the Mark 10 Decca was born. Before modifying the ground stations it was decided to add a further 5 : 1 stage of ambiguity resolution for zone identification by transmitting an additional frequency— $8.2f$ —so that the difference between that and $8f$ would provide a $0.2f$ pattern.

This meant transmitting five frequencies simultaneously from each station in turn and since even the highest of our aerials (325 ft) were only a small fraction of the average 3000 m wavelength, transmission efficiency depended on the Q of the coils comprising the five tuned circuits. O'Brien produced a unique design having an average Q of 3000. Of course there were a few other little problems like ensuring that four times per minute three stations went off the air and the remaining one radiated five frequencies in a precise phase relationship. In due course the various problems were solved and

practically all the existing Decca Navigator chains, together with all marine and airborne receivers, use this technique which is now known by the name 'multipulse'.

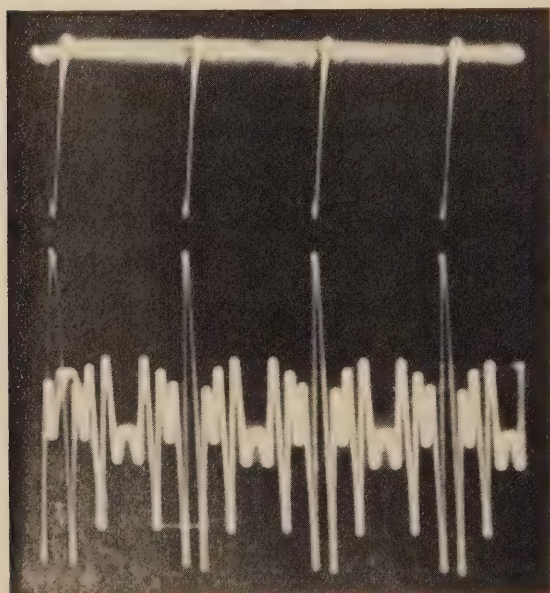
The multipulse principle consists in summing the four c.w. signals received from a given station and this produces a pulse signal recurring at the fundamental frequency f (obtained in the earlier method as a beat frequency) as shown in Fig. 2(a). In contrast with an actual pulse transmission which occupies a wide bandwidth, this pulse is synthesized from four harmonic frequencies received through highly selective crystal filters. It has the important property of remaining stable even when large phase shifts are applied to the individual components as occurs in skywave/groundwave interference conditions. Figure 2(b) shows the unaltered phase of the pulse with respect to the upper reference trace in the presence of phase shifts of $+16^\circ$ on $5f$ and $8f$ and $-16f$ on $6f$ and $9f$ which typify the limit of reliable lane identification by the beat-frequency method.² This development reversed what had been a shortcoming of the system and gave the lane identification a higher integrity, under night conditions near the coverage limit, than that of the fine lane pattern.

Turning to more general matters, Decca can be described as a frequency multiplex system. During the war, Post Office engineers invented a time multiplex system called POPI in which a pair of stations transmit the same frequency but only one station is on the air at a time. It seemed to me that while this might pose problems in a fast aircraft flying across the pattern, it would be ideal for a long-range tracking system where the aircraft would fly 'to' and 'from' the pair of transmitters. With frequency multiplex, the night-time range is limited to that range where skywave amplitude approaches 50% of the groundwave, but with both stations operating on the same frequency it should be

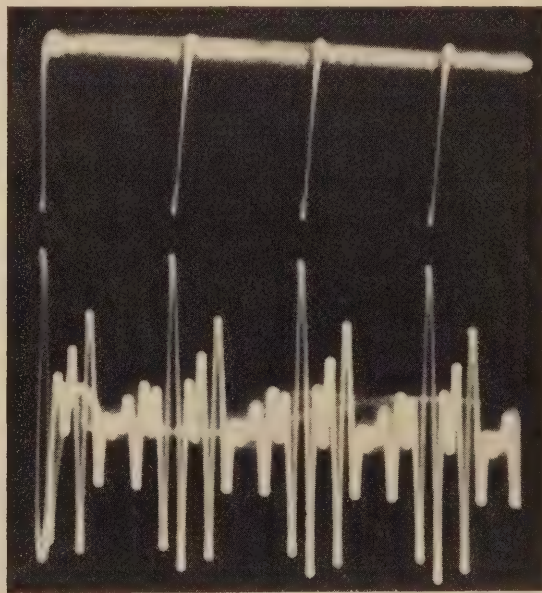
possible to use the skywave and skywave variations should tend to cancel along the right bisector of the baseline. By setting up a pair of stations either side of Gander and another pair in Britain, two accurate tracking patterns could be provided for aircraft crossing the North Atlantic and this was done to form the experimental Dectra system.³ Decca 'purple' frequencies were used for the two pairs and a 'ranging' hyperbolic pattern was also generated between the two master stations to give position fixing along the ocean routes. The two 'tracking' pairs each formed the 'purple' baseline of a normal Decca chain so that, at each end of the Atlantic, aircraft had full Decca facilities and a single receiver unit could be used for short- and long-range navigation.

To make maximum use of the Decca/Dectra system, a digital computer⁴ and a fully-automatic Flight Log,⁵ giving pictorial display of aircraft position, were developed. This combination enabled a pilot to fly from the coverage area of any European Decca chain to America. For instance, he could switch on and bring up the appropriate chart in Copenhagen and fly to New York with no workload—chart changes and chain frequency changes being completely automatic—and have continuous position fixing to an accuracy of a few miles en route and a few hundred feet at the terminals.

I then became convinced that accurate navigation with continuous position and routes automatically displayed to the pilot would enable aircraft to be run like trains—take-off on time, fly accurately a route designated by ATC, and have ETAs for reporting points fed into the computer. Speed could be controlled and aircraft could fit into the time slot planned for their arrival. Holding and delays would thus be eliminated. Every aircraft in a holding pattern is occupying valuable airspace and contributing to inefficiency and delay of all other aircraft in the area. This was considered 'too



(a) Three cycles of waveform, no phase shifts applied.



(b) $5f$, $8f$ components shifted $+16^\circ$; $6f$, $9f$ shifted -16° .

Fig. 2. Effect on Decca multipulse waveform of phase shifts in components.

revolutionary' at the time but it is now part of the general philosophy that has become known as Area Navigation. But Area Navigation today is still limited by the inaccuracy of the VOR which is fed into the computer.

I also felt that there should be redundancy in the supply of aircraft position information to the traffic controller, and I asked for the development of a non-synchronous data link so that the controller could see superimposed on his radar screen the identity and position of each aircraft as determined by its navigational aid. Bernhard Parker invented just such a system and it worked perfectly.⁶ Many demonstrations were given and the two Decca Company aircraft always flew with the data link working so that traces plotted from it on the ground could be compared afterwards with those from the Flight Logs in the aircraft. Sometimes gaps occurred in the ground trace but never an error, and over some five years it was estimated that billions of fixes were 'data linked' to the ground. The link also handled simple instructions and acknowledgments between our ATC and the pilot.

For world navigational coverage we proposed, some 20 years ago, a v.l.f. time-multiplex system called Delrac. (I described both Dectra and Delrac in a paper I gave to a meeting of the American Institute of Navigation held on 29th April 1954 in Baltimore, Md.⁷) A basic frequency of 12 kHz was chosen as the best evidence indicated that this would result in the skywave and groundwave being approximately in phase at that distance where the two components were of equal strength. To be reliable under all conditions, it was decided that lane identification should take place in 3 : 1 steps. Fourteen pairs of stations were proposed for the coverage of world routes, so situated that signals from each station of a pair would be received under similar conditions (day or night) so as to avoid diurnal effects. After trials of their Radux I and Radux II, which were unsuccessful for fundamental reasons,⁸ the US Navy decided to develop Omega. This was similar to Delrac and included the 3 : 1 lane identification, but only eight transmitters were specified for world coverage, thus necessitating corrections for diurnal effects which can be of the order of 40 μ s. In sophisticated receivers, these corrections are in the computer store and are applied automatically, but of course their effectiveness is liable to vary for a number of reasons. It is interesting that in a recent paper on Omega,⁹ the following statement is made: 'The best result achieved in this twilight flight was 2.8 n.m. c.e.p. and a 4.1 n.m. 95% error.' Decca has always used a criterion which tends to indicate the 'worst' rather than the 'best' figure when referring to the accuracies of its various nav aids.

The only widely used navigational aid I have not so far mentioned is Loran C.¹⁰ O'Brien obtained fundamental patents on this system and Decca won a patent suit against the US Navy in the US Court of Claims in 1969. Unfortunately an appeal court reversed that decision. O'Brien invented this system in 1947 when we were searching for the ideal method of lane identification for Decca. I remember asking 'Why can't we send out pulses from master and slave stations to identify the

cycles?' The answer was that so much bandwidth would be required in a frequency band already overcrowded that an allocation would never be granted. I told O'Brien to put in the patent application anyway. Full credit must go to the US authorities (principally the US Coast Guard) for persevering in the development of Loran C, solving the many technical problems and being powerful enough to get the frequencies allocated. I was fortunate to secure for Decca the first US Navy contract for the development and production of the receivers. Since then Decca has continued Loran C development and its latest air and marine receivers are completely automatic in operation. Having reached this stage of development, one must of course compare Loran C with Decca and today there is little to choose between them. Loran C can now automatically and fairly reliably identify the correct cycle in the pulse envelope, at which phase is to be compared, and provides the same order of accuracy as Decca. It has the great advantage of performing, in principle, as well at night as in the daytime since the skywave pulse arrives later than the groundwave and can be gated out on that basis. But Decca, used within its limits (under 240 n.m.), has its stations much closer to the operating area and for this and other reasons it can be expected to have the edge in accuracy and to be more reliable under all conditions.

The receivers for the Decca system are cheaper and easier to use than even the modern Loran C receivers, and since they are so well-liked by users (fishermen attach great value to their secret logs of Decca fixes), it is very improbable that Decca could be replaced by Loran C for close-in navigation. Loran C, however, is unique in providing both long-range and short-range high-accuracy position fixing and it is my choice as the eventual area coverage system for aircraft. Its cost of installation, operation and maintenance is only a fraction of that needed for VOR/DME and it can provide the better accuracy that is needed for close lateral separation of air routes.

I have the same complaint about the implementation of Loran C as I do for Omega. The Americans always want to get too much out of their systems, as with the eight stations for Omega world coverage compared to our proposed 28 for Delrac. Similarly, 1000-mile baselines are typical for Loran C when far greater reliability, especially in automatic cycle identification, would be obtained with, say, 400-mile baselines. There would be little difference in cost because of the much lower power required for the smaller coverage.

Prior to the introduction of the principal ground-based hyperbolic fixing systems that I have been discussing, ships and aircraft had to rely on 'point source' beacons. Originally these were simple radio transmitters operating in the m.f. band, placed at known geographical positions so that the user could get bearings on them by d.f. Later, more sophisticated systems were introduced for aircraft, such as the four-course range and VOR (V.H.F. Omni-Range) to provide a more accurate and reliable service. VOR coupled with DME (Distance Measuring Equipment) is now the international standard short-

range navigational aid for commercial aviation. Its range is of course limited to line of sight and despite impressive technical improvements such as Doppler VOR, its overall accuracy is not considered suitable, for instance, for safely defining two tracks in a 10-mile airway.

The new position fixing systems, which their proponents expect to eventually replace all other aids, are based on the use of satellites. The US Navy Satellite System (formerly Transit)¹¹ has been in operation for some years and its intended successor NavStar¹² will start operation in the early 1980s and is scheduled to give complete coverage, using 24 orbiting satellites, by 1984.

Space does not allow me to describe the features of these systems in more detail but technically they are of great interest and they represent, almost literally, a new dimension in the technology of radio aids to navigation.

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Radar: Some personal recollections

P. A. ALLAWAY, C.B.E., D.Tech., C.Eng., F.I.E.R.E.

Wartime radars used by all three Services are briefly described and their contributions towards post-war development indicated. The second part of the paper deals with proximity fuzes, army radars, and airborne reconnaissance equipment.

Looking back can be more difficult than looking forward. In 1925, when the forerunner of our Institution was formed, I was a schoolboy who had graduated from crystal sets and was absorbed and often frustrated by the complexities of reaction circuits. If I had given thought to the future I am sure I could not have anticipated in any way the evolution of electronics as we understand it today or, indeed, the way in which the advent of the technologies would affect our lives in so many different ways.

My first association with the application of electronics to remote location arose from acoustic sound locators which were the original devices for the ground-based location of aircraft.

Shortly after the outbreak of war I was engaged with the development of the GL Mark 2 radar. This was a metre wavelength set to provide warning, bearing and range for anti-aircraft fire control purposes. The whole equipment, although mobile, must have weighed at least 20 tons and consisted of two large trailers containing the transmitter and receiver together with a very powerful diesel electric set providing enough energy to light a small town.

In retrospect two aspects of this experience stand out in my memory. The insistence of the Army that the equipment should be 'soldier-proof'; today this would mean consideration of the man/machine interface, in those days it meant protecting the equipment against damage from ammunition boots and rifle butts! At the other extreme the aerial designers were insistent that the lengths of the coaxial cables should be electrically, rather than mechanically, correct to obtain the required elevation polar diagram.

This experience was followed by my first association with Naval radar, I believe it was the Type 271, a centi-

metric equipment involving the design of large parabolic reflectors and manually driven turning gear with the whole of the massive assembly on top of a 70 ft mast.

I was responsible for the installation of the experimental equipment on board HMS *Wallace* whilst she was refitting in the Dockyard at Leith. This proved to be a very illuminating and worthwhile experience from which I still have vivid memories of a Shipwright armed with a piece of chalk and an oxy-acetylene cutter removing and repositioning a significant part of the ship's after structure in the space of one morning. He did it without any drawings and he had certainly never heard of a Quality plan.

About this time, and perhaps because someone thought I needed a quieter life, I became concerned with the development of the first Naval p.p.i. display. This used rotating deflexion coils with a magflip drive and perhaps my previous experience of Army equipment had impressed upon me the need to save weight wherever possible, certainly sailors did not wear ammunition boots. As a result I decided to design the rotating deflexion coil assembly using an aluminium casting. When switched on, the p.p.i. worked exceedingly well except for the fact that the calibration rings turned out to be rectangular rather than circular. This resulted in an investigation leading to the conclusion that the specification for DDT428 was a sound specification in all but one respect and that, after all, traditional Naval brass contained less magnetic impurity.

My association with Naval radar continued with a secondment to the Admiralty Signals School annexe at Witley where, for the first and only time in my life I became a member of a sanatorium whilst participating in the early design work which was to result in the Type 262 series of Naval fire control radars (Fig. 1).

My first real association with airborne radar started during 1944 when the requirements for small centimetric ASV (air to surface vessel) for carrier-borne aircraft became apparent and, at this time, I was seconded to TRE for work associated with radar intended to go into Fairey and Short Bros. carrier-borne aircraft.

By this time considerable advances had been made in component design and many really miniature components were becoming available from British and American sources. The design of microwave components had advanced substantially and all these techniques were utilized together with much competent mechanical design to achieve a completely self contained ASV with a fully

Dr. Percy Allaway (Fellow 1971) is Chairman of EMI Electronics Ltd. He first joined the Group in 1930 and returned to it in 1939 to work on military radar systems. He serves on many industrial and government Committees including the National Electronics Council on which he represents the Conference of the Electronics Industry. He is the Institution's representative on the Board of CEI and a member of its Executive Committee. Dr. Allaway has been closely associated with Brunel University since its formation and is a member of its Court; the University conferred its Honorary Degree of Doctor of Technology on him in 1973. He has served on the Institution's Council since 1972 and was first elected a Vice-President in 1973.

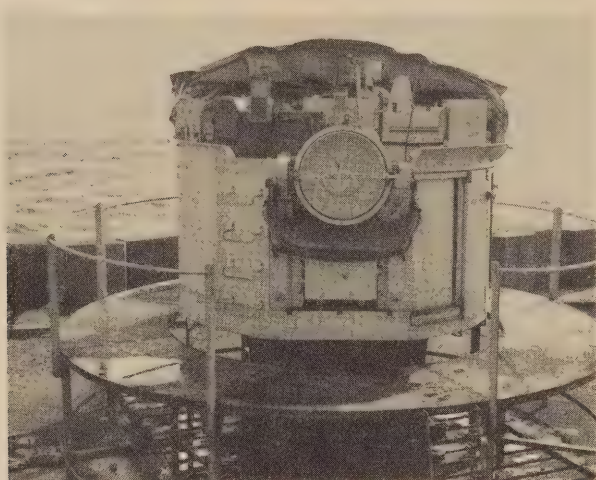


Fig. 1. Naval radar type 262R.

stabilised aerial system. An experimental model was made towards the end of 1945 when the work was abandoned to be resuscitated later as ASV15.

So much for my personal involvement during the formative years of radar.

Almost as soon as radar was shown to work, people began to think of ways of improving it and adapting it to different operational needs. The early metric radars were useful for fairly long range detection and distance measurement, but not much good for measuring bearing. Nevertheless there were some early 200 MHz Airborne Interception (AI) sets using split beams with sequential switching, and our Research Laboratories were brought in to improve short range detection (a problem still with us in g.w. proximity fuzes!) and subsequently to engineer the first attempt at automatic signal processing (A.I. Mk. VI), whereby the pilot of a single-seater aircraft could be presented with a pictorial display enabling him to intercept an enemy plane at night. Flight trials were not without incident, including one occasion in 1941, flying in a *Blenheim* from Christchurch, when the navigator's machine gun, in the floor in front of his seat, fell into the grounds of the 'Cat and Fiddle', perspex 'bubble' and all!

Meanwhile, centimetric sources were being developed enabling useful bearing resolution to be obtained with dishes small enough to go in an aircraft. The most important was the cavity magnetron, but a pulsed klystron with $\frac{1}{2}$ kW peak was developed at EMI and used in early experimental versions of the history-making H2S navigation and bombing radar. Eventually it was decided to use a magnetron in order to increase the range, in spite of the risk foreseen (and justified in the event) that the enemy would copy the magnetron as soon as a bomber was forced down in his territory.

The first 60 H2S equipments were rapidly manufactured, entirely assembled and tested in the Research Laboratories, and fitted in Air Vice Marshal Bennett's famous Pathfinder Squadron.

I have already mentioned my own connection with the Naval type 262 radar, which was for target aircraft

tracking for AA gun direction. EMI Research Laboratories were also heavily involved with this from 1943, both on the design of the centimetric r.f. side and on the signal-processing side. This radar used a pencil beam at a slight angle off the bore-sight and rotated about it. Correlating the echo strength variation with the beam rotation gave azimuth and elevation error signals used in a servo-system to centre the bore-sight on the target. The echo was also automatically tracked in range by an electronic strobe pulse. These automatic tracking features are still the basis of radars for gun and guided weapon direction, although nowadays they use a 'monopulse' system for angular tracking, in which four beams are received simultaneously, each one off-set from the bore-sight by the same small amount, respectively up, down, left, and right. Taking the ratios of the signals in each pair gives error information independent of fading, which can be troublesome with the earlier rotating off-set.

Another class of radar which was started in our Research Laboratories during the war, but not completed until after the war, was the Naval type 992. This was a centimetric radar for surveillance and target designation. The 360° surveillance requirement indicated a rotating beam, with p.p.i. (map) display, but the requirement for target designation needed an ability to track targets with sufficient accuracy to allow a gun direction radar (e.g. type 262) to find the designated target. This 'track-while-scan' facility was only possible, allowing for actual target rates of turn, with the quite high rotation speed for the 3m dia 'cheese' aerial, of 90 rev/min—a fearsome sight!

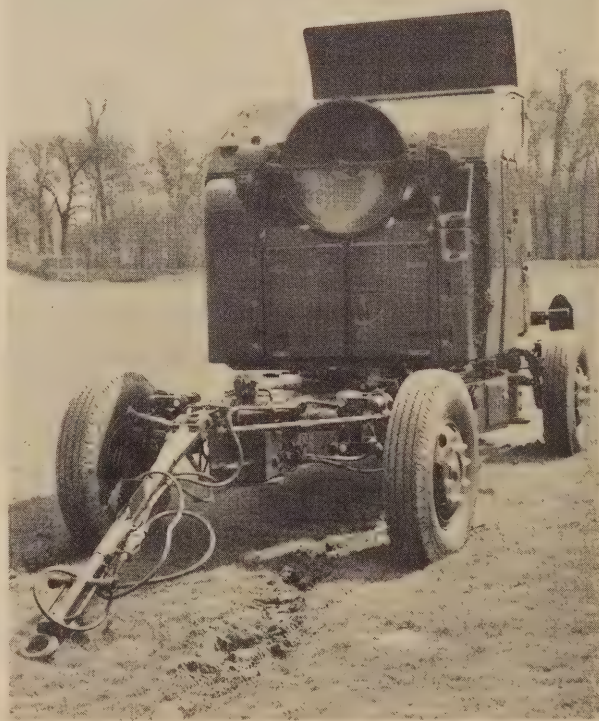


Fig. 2. *Blue Diamond* radar and *Yellow Fever* predictor. Note the two aerials.



Fig. 3. Mortar locating radars: Left—*Green Archer* generator. Centre—*Green Archer* radar. Right—*Cymbeline*.

There was a slow-down after the war both in numbers of projects started and in the rate of progress of each one. As a result of war-time experience with reliability, much more care was taken with environmental testing for such items as temperature, humidity, mould growth, shock, and vibration. Also, the Ministries now had time to be particular about the choice of components, and to insist on standardizing various things, including drawing procedures. So a typical time interval now from the stating of an Operational Requirement to Service use of the resulting equipment is ten years.

This has all sorts of bad effects, ranging from the fact that by the time it is in service the equipment is often obsolete at least in its technology and sometimes in its operational need, to the frequent frustration of people concerned with it and the possibility that a man might only have experience of four projects during the whole of his working life!

In radar work in EMI, since the war, we have specialized in three main areas: field army radars, airborne reconnaissance, and radio proximity fuzes for missiles. The growth of all these can be traced from the various war-time projects already mentioned.

Take proximity fuzes first. It may be argued that these are not radars in the sense usually understood, but I propose to include them on the grounds that they transmit energy and detect the presence of a target by means of the energy reflected from it. For shells, especially in the early days when thermionic valves were the only active

devices available, the radar had to be the simplest possible, and comprised a c.w. oscillator which also acted as a homodyne detector. Since there was necessarily relative velocity between shell and target, the output of the detector was a Doppler frequency at a few kHz, and a crude filter could isolate this from other components. Such shell fuzes are still being made by the agency factory managed by EMI Electronics Ltd., but naturally solid-state devices are replacing valves and making it possible to have more elaborate fuzes.

EMI has designed and manufactured radio fuzes for the majority of the UK surface/air guided weapons. The first generation of these, used in *Thunderbird* (Army) and *Bloodhound* (RAF), were Doppler fuzes broadly similar to shell fuzes, but were given much more constant sensitivity out to their useful maximum range by a technique involving frequency modulation.

Development of improved types of proximity fuze has depended very greatly on applied research, in particular the setting up by EMI of a radio-modelling facility, in which the performance of new fuze systems is assessed by using scale models of targets and scaling down the carrier wave-length in the same ratio. This facility, the only one in the UK, is now being used for assessing other radar systems besides fuzes.

Environmental testing is particularly important for fuzes, which may have a shelf life of years, perhaps under tropical conditions, before being required to operate. Then they have to work first time, possibly in arctic

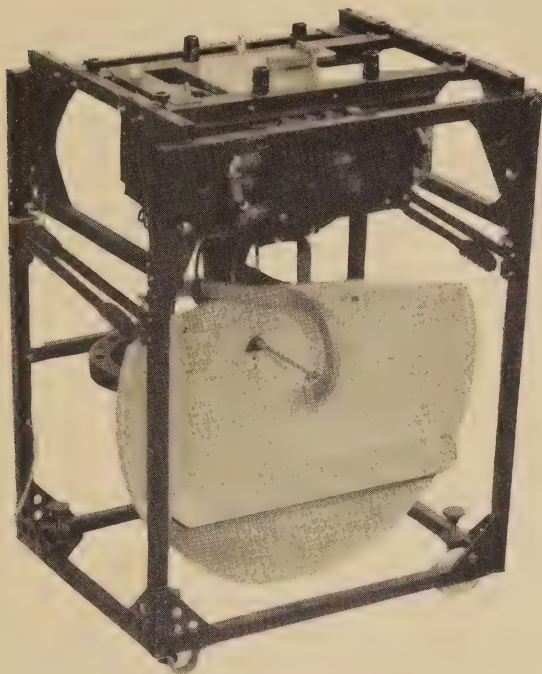
conditions, and not fail or fire prematurely under severe vibration. So we had to build up a very extensive test facility. This can only subject the fuze to a simulated environment, and when it comes to flight trials in the weapon, we had to evolve telemetry systems in order to find out what was actually happening during flight, both to the environment and to the equipment behaviour. This telemetry was naturally used also for monitoring the propulsion and guidance systems in the missile.

Turning to radars for the Army, in 1949 a target tracking radar for anti-aircraft guns, called *Red Indian*, was started. This had a rotating pencil beam, and could be regarded as similar to the Naval type 262 already mentioned, but for land use, mounted in a trailer. It

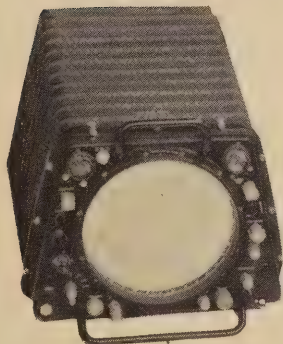
relied on visual target acquisition, and was not put into production, but led in 1952 to an improved version known as *Blue Diamond*. This had an acquisition mode in which the same transmitter and receiver (TR) were first switched to a second aerial giving a raster scan of a pencil beam. When a target was seen, its co-ordinates were noted and used to point the tracking aerial system, to which the TR was then switched. The raster scan was provided by a 'Foster' scanner, which is an ingenious way of producing a rapid azimuth scan (20/s) of $\pm 20^\circ$ by means of a constant-speed rotating mechanism. A simple nodding arrangement provided a lower speed elevation scan. The whole equipment formed part of a director called *Yellow Fever*, for the L70 AA gun, and



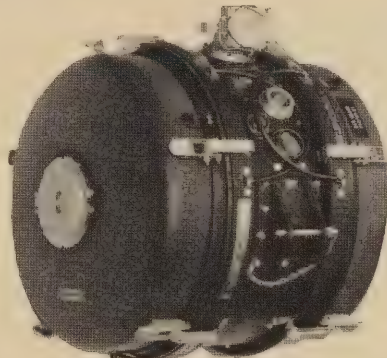
Fig. 4. SLR radar type 391 from Phantom reconnaissance pod: (With acknowledgment to the MEL Equipment Company Ltd. for items (b), (d), (f), (g), (h).



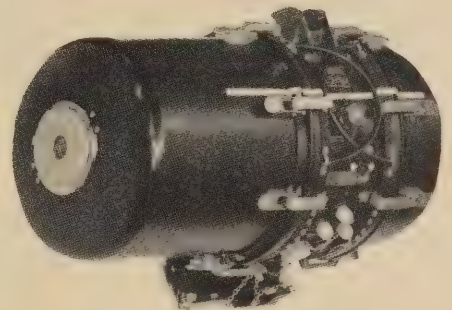
(a) Aerial (on servicing frame)



(b) Display unit



(c) Transmitter/receiver



(d) Modulator

Fig. 5. Airborne radar type ASV21E. Major units

we also made the electro-mechanical predictor included in it. The development was complete by about 1955 and some three dozen sets were manufactured (Fig. 2).

As soon as the fast Foster scanner was available, RRE carried out a successful experiment to see if by locking the elevation scan, mortar shells could be detected as they passed through the planar sector sweep. This led to the mortar locator radar known as *Green Archer*, which was developed between about 1955 and 1958. The principle used is to set the elevation angle so that the sector sweep is just above the horizon, and when a mortar shell is seen, to note its bearing, range, and time of occurrence and immediately increase the elevation by a pre-set amount of a few degrees, subsequently noting the bearing, range, and time of the second interception. Assuming a ballistic trajectory, a fairly simple analogue computer is used to extrapolate the trajectory backwards and hence determine the mortar location as the point of intersection of the trajectory with the ground.

Green Archer was very successful, and has been sold to many countries besides the U.K., both in its original version on a trailer and mounted in armoured vehicles.

However, the style of construction used was conventional for 1955, and resulted in an all-up weight including power supply of 6 tons. It was believed that by using something more akin to aircraft structural techniques this could be very greatly reduced, and after a period of experimenting we started development in about 1964 of *Cymbeline*, a mortar locator with a substantially identical performance specification to *Green Archer*, but having only one-sixth of the weight (Fig. 3).

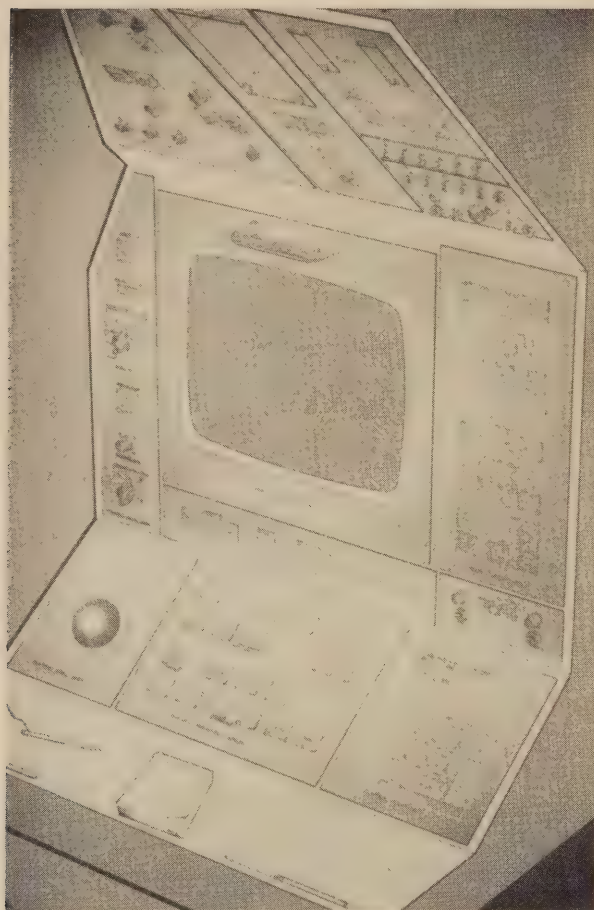
Since this project seemed likely to sell abroad even better than *Green Archer*, as has indeed proved to be the case, EMI was selected by H.M. Government as the guinea-pig for a scheme in which development funding was shared. Much work has been done, in one case with EMI leading a multi-national team, and is still proceeding, on the design of even more advanced weapon locators.

Airborne reconnaissance started with the war-time H2S Mk. 1 and 2. I am lumping under the title 'reconnaissance' all three ways of utilizing information from the map display, namely (a) navigation, (b) attack, and (c) recording of information for later study. H2S

was intended for (a) and (b). Subsequent Marks included Mk. 4, in which a Mk. 14 Bomb Sight was incorporated into the system, and Mk. 9 for the V-Bombers which is still in Service use.

For (c) the rotating beam and p.p.i. display is unsuitable, and Sideways Looking Radar (SLR) was used instead. This scheme was first used on the early metric ASV Mk. 2. It has a fixed beam normal to the aircraft axis, using the forward motion of the aircraft to provide the second co-ordinate (echo arrival time provides the first). Because the aerial is a fixed array along the side of the aircraft, it can be long enough to give a very narrow beam, which improves the resolution, and the system leads to a convenient way of recording the signals photographically on a moving film, providing a strip map.

We made various experimental SLR radars, including one for the ill-fated *TSR2*, which was later very successfully adapted to form one of the equipments carried in



(a) Display



(b) Radar mounted on Nimrod

Fig. 6. Searchwater radar

the reconnaissance pod for the *F4 Phantom*, for which EMI also did the system management (Fig. 4).

We have developed various Marks of ASV, of which Mk. 21 has had the longest run, and is still in use as Mk. 21D (Fig. 5). It is an adaptation of H2S Mk. 9. However, performance of this basically simple radar (not different in essentials from the war-time ASV Mk. 3) leaves something to be desired as regards detecting submarine periscopes or even 'snorts' in a rough sea, and a much more sophisticated radar (*Searchwater*) is under development for the *Nimrods* of Strike Command. This uses all the modern tricks of pulse compression ('chirp')

to increase range resolution while maintaining mean transmitter power, pulse-to-pulse integration, scan-to-scan integration, constant false alarm rate, etc., and is showing very promising results in trials (Fig. 6).

As regards the future, I think this must lie mainly with making still more use of all the information contained in the signals received, not only from individual pulses, but by correlation of signals from many pulses. Most of the theory of what can be done has existed since soon after the war, but its practical realization has awaited electronic component development, particularly l.s.i. random access memories. These now exist in a form and at a price which makes many of the desired system operations practical. But in another area practice lags far behind theory, namely aerial array-processing, in which mechanical movement of an array or reflector to steer a beam is replaced by electronic control of the relative phasing of the elements of a fixed array. Besides the advantage of having no moving parts, the main virtue of such an arrangement is the ability to interlace sets of pulses doing different jobs, e.g. a slow search scan over the whole angular field and one or more tracking operations on selected targets.

A technique which is particularly applicable to airborne reconnaissance is 'aperture synthesis', in which forward motion of the aircraft is utilized to give the effect of a much longer sideways-looking aerial than is physically possible, leading to very good angular resolution. More will be seen of this in the future. It is an example of greater use of pulse-to-pulse correlation mentioned above.

It is unwise to try to prophesy too far ahead so I will leave it at that, but I am sure we shall see many interesting developments in the next decade.

Acknowledgments

Most of the work described has been done under contract from HM Government, and there has been excellent technical co-operation with the Ministry Establishments, especially RRE, RAE and ASWE, RARDE, and their fore-runners. Many, but by no means all, of the ideas mentioned above originated in these Establishments.

Also, where I have said that we made an equipment, parts of it (e.g. in a few early instances, the aerial) may have been made, and possibly designed, by other firms, not under sub-contract.

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Present-day Control Engineering— Is it latin to the undergraduate?

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The development of control engineering design techniques over the last two decades is traced and their application is examined to show how they may be reflected back into the undergraduate teaching of engineers. Control engineering can be regarded as a thought-provoking orderly discipline fulfilling the same functions for science students as does latin to the arts student.

Introduction

Once upon a time, during the Second World War, the objectives in control engineering were clearly defined in the shape of the advanced weapons (for that time) needed to ensure the survival of some nationalities of mankind and the partial extinction of others. The explosion in knowledge which accompanied the development of the new weapon systems was openly revealed at the end of hostilities, and is best exemplified by the contributions of Tustin,¹ James, Nicols and Philips,² and MacColl.³ This new knowledge, coupled to the previously available literature of Maxwell⁴ on governors, Minorsky⁵ on ship steering, Hazen⁶ on servomechanisms, and Bode⁷ and Nyquist⁸ on feedback system stability, generated an ever-increasing interest in the subject, fanned by the desire to increase system effectiveness and fed by exciting developments in computer technology which has made manned space flight possible only some twenty years after the end of the Second World War. For those relatively few professional engineers privileged to specialize in control and related topics, the reward in the last few decades has been one of immense technological stimulation, coupled with pride as techniques initially developed as control devices have found software and conceptual applications in areas of biomedical systems,⁹ management,¹⁰ training,¹¹ purchasing,¹² and national economics.¹³

This growth in interests has been reflected into United Kingdom undergraduate courses, and we have now reached the stage where some aspects of control and systems engineering, unpopular though it may be with some students, are taught to the vast majority of engineering undergraduates whether their degree course be

notionally named chemical, electrical, electronic, mechanical, aeronautical, production, or industrial engineering. In 1973, for example, some 4500 engineers graduated from United Kingdom universities and polytechnics in these disciplines.¹⁴ Most, if not all, have a knowledge of control fundamentals. To obtain the full numerical picture, at least some physics, mathematics, and maritime studies graduates must be added to this estimate, so that the potential pool from which professional control engineers may be drawn is now exceedingly large, and far outstrips the demand. Despite the tremendous job satisfaction experienced by the lucky(?) ones, why should we teach them the subject when the chances of employment as a control specialist are so slight? Incidentally, in non-vocational degree courses the answer would probably be 'for the good of the soul', but this is not a convincing argument as seen by the engineering undergraduate who already has an excessive number of calls on his study time. To answer this question we must trace the development of control engineering through the last three decades, so that we can see the subject in a new perspective, and restate the important principles we should teach in the light of this new perspective.

The main wartime interest was in devices called servomechanisms,^{15,16} which found their use in computing devices, gun drives, radar tracking loops, stabilization platforms, missile control surface actuators, aircraft power controls etc. Some of the wartime expertise passed directly to the Royal Military College of Science, Shrivenham. When the author joined the College in 1962, the Guided Weapons and Staff Courses were well established and in many ways these courses could be regarded as leaders in the field. The well-defined student end-product with the specialist project officer at one end of the spectrum, and the general (pun not intended, but often true!) officer with a passing knowledge of systems at the other, was conducive to the development of a wide range of novel laboratory experiments, and to a unique collection of textbooks. Quite apart from the English Universities Press Series, whose authors extended throughout the College, the teaching of servomechanisms and related topics has led to no fewer than six texts, appearing at the rate of two per decade in the following order; Porter,¹⁷ Lawden,¹⁸ Pearson,¹⁹ Hollingdale and Toothill,²⁰ Towill²¹ and Garnell.²² Such enthusiasm for the printed word amongst a group of scholars may be common in the American engineering faculty, but in the

Professor D. R. Towill (Fellow 1970) was appointed to the Chair of Engineering Production in the Department of Mechanical Engineering and Engineering Production in the University of Wales Institute of Science and Technology at the beginning of 1970. He is a graduate of the Universities of Bristol and Birmingham and before joining UWIST in 1966 he was a senior lecturer in automatic control at the Royal Military College of Science. He has held a number of industrial consultancies and was for some years with the then Bristol Aircraft Company as a dynamic analyst. Professor Towill is the author of numerous papers and books, and five of his papers have gained Institution Premiums. He is chairman of the IERE Automation and Control Systems Group Committee.

United Kingdom it is well nigh unique. Slowly, the emphasis on technique and application may be seen to change as these successive books are compared, but the texts predominantly reflect the urgent necessity to train serving officers to communicate with industry as well as with the various research establishments. The current interface problem must be solved!

The Non-linear Era

The decade which ended in the early 1960s saw some remarkable advances in the understanding of non-linear system behaviour. This included the intentional use of system non-linear characteristics in an optimum manner via time domain analysis,^{23,24} design of optimum systems to achieve the desired linear performance whilst accepting stochastic constraints on plant excitation,²⁵ and describing function methods for frequency domain studies of system stability and response.^{26,27} The realization that in non-linear systems, performance improvement could be obtained by deliberately injecting a stabilizing signal,²⁸ led to the concept of the 'dual input describing function',^{29,31} for the design of such systems. 'Limit cycling' properties of a class of non-linear systems were then put to good use in an adaptive scheme devised to keep the limit cycle amplitude and frequency constant in the light of changes in the plant under control, the limit cycle then acting in similar fashion to the carrier frequency in an a.c. system.³² Describing function techniques were also successfully initiated into the random signal field following Booton.³³

This decade also resulted in a wealth of texts devoted to various aspects of non-linear system analysis³⁴⁻³⁷ and three texts on linear systems, totally different in concept to each other, but each making a profound impact on the subject. One by Evans³⁸ described the root locus method thus offering the engineer for the first time a design tool which promised to control both time and frequency responses simultaneously to his satisfaction, the second, by Horowitz,³⁹ dealt at length with system structure and sensitivity, and the third, by Canfield,⁴⁰ fully exploited the integration of Bode plots and root loci into system design as originally developed independently by Kan Chen⁴¹ and Biernson.⁴² The latter also showed how saturation effects could be allowed for using a Bode plot analysis⁴³; Canfield also considered non-linear effects via the describing function in his text.

Decade of Change?

Joining the UK University system as a faculty member for the first time at the end of this non-linear era, the author soon found that the new student audience was far less captive than in his own student days a decade earlier. Already, signs were beginning to emerge that engineering graduates were looking beyond the engineering profession for career opportunities, and into such activities as accountancy, airline piloting, banking, and income tax inspection. Students were also noticeably more belligerent and legalistic minded, as the author found to his personal cost when manoeuvred into a position where he had to teach an additional honours control course *ab initio* with only 60% of the final year

timespan left, the students objecting to the original course offered on a legal technicality which had little to do with the academic merits of either course. It is a fact that student power can thus result in much burning of professorial midnight oil with no escape clause.

By 1966 the word had spread like wildfire amongst University academics that control engineering was a 'with it' subject, an indispensable stocking filler to the undergraduate curriculum in the final and penultimate years, and even, in at least one case the first undergraduate year. But the literature itself was changing rapidly, fanned by the advent of modern control theory. Most control engineers see a sharp distinction between 'modern' and 'classical' control theory, their opinions generally being flavoured according to whether they are designers or researchers. In practice, opinions are not as black and white as many believe; indeed, it may be difficult to obtain universal agreement on the dividing line between 'classical' and 'modern' techniques. One definition of modern control theory is the use of state functions and matrix methods, but an alternative might be to regard modern control theory as the development of computer-orientated methods of analysis and design (as distinct from the automation of any existing manual techniques). The latter definition would bring together many apparently strange bedfellows, but the parameter plane⁴⁴ is essentially a computer-orientated technique aimed at dominant root positioning, so why should it not be regarded as a direct competitor with pole placement methods?⁴⁵ Furthermore, it is wrong to consider the design of compensators via the minimization of quadratic performance indices based on deterministic performance criteria⁴⁶ as 'ancient', not simply because it is in fact recent, but because it is relevant to current design practice.

Many of the avenues of modern control theory pass through the contributions of Kalman,⁴⁷⁻⁴⁹ who, besides having the gift of innovation, also has the even greater gift of realization of the relevance of his findings. In some parts of the USA his thinking has so dominated research that rumour has it that the word 'Kalman' appears as a keyword in thesis titles more frequently than any other word. One cynic has remarked that 'Kalman' appears in such titles more frequently than 'the'! In 1971, the importance of the Kalman filter was already such that it had become difficult to sell a navigation system in the USA without one incorporated, although it was conceded that in Europe it might be equally difficult to market a navigation system with one incorporated!⁵⁰

Although the new discoveries were included post-haste in university and short courses, the traditional design methods have yet to be discarded like the proverbial old boot. Ten years later, industry, in general, has remained unimpressed, preferring to use root locus, Bode, and Nichols methods. For example, in the 1973 IEE Computer Aided Control System Design Conference, despite strenuous efforts by the Organizing Committee, only two papers appeared wholly from industry, and those were both concerned with computer implementation of long-established classical techniques.^{51,52} Apart from inter-

face problems between research workers and practising designers, this state is due to industry proceeding with due caution. Indeed, it would be crazy to do otherwise when the designer's head is at stake. He must use his *a priori* knowledge of systems and extrapolate from this datum. New techniques must be introduced in parallel with existing so that we may build up our own case histories before placing complete confidence in our new approach. We must not bury our heads in the sand either way, by being too complacent about our existing techniques, or too ready to use the new. Rather we should seek the best of both approaches, as will be illustrated later. Further proof on the relatively slow rate of adoption of new design techniques by industry is given by Noton⁵³ in a chapter reviewing the practical significance of results of modern control theory and potential applications.

Classical versus Modern Control Theory

Horowitz and Shaked,⁵⁴ in a 'perspective' paper, again re-emphasize that in linear time-invariant feedback system design, the real problems are caused by sensor noise, loop bandwidth, and plant uncertainty. These problems impose practical constraints and considerations which are readily solved using classical techniques (such as Nichols charts). In contrast, the authors argue, with suitable mathematical support, that the following topics which have received immense study via state space methods—namely, eigenvalue realization by state feedback; observers for states which may not be sensed; decoupling theory; sensitivity theory; controllability and observability—have contributed little or nothing to solving problems with these practical constraints. Furthermore, the authors further argue, the real problems are obscured in state space notation. Powerful sentiments indeed, but is there not a danger that too much design intuition is required using classical techniques, whereas we may be able to rely on mathematical formulation in state variable form to help put that old head on young shoulders! Perhaps authors in classical control theory have unnecessarily failed to show that practical constraints *can* be incorporated from stage 1 of the design, rather than added as an appendage almost as an after-thought.

It should be remembered that only a few percent of the various design techniques developed in the classical control era have survived the test of time. Probably the greatest single source of classical data, the journal *Applications and Industry*, has many examples of papers which have disappeared without trace. Eventually, (but not yet), time will provide the same filter for modern control theory contributions, clearly identifying the few outstanding papers published during this decade as the design aids for the next generation. History, and not prejudice, may also explain why relatively few papers using classical techniques are published in journals requiring theoretical innovation as a main criterion for acceptance; we know the very highest standards have to be met, because the 'norms' are so clearly established, whereas in modern control theory, mathematical elegance, as Horowitz and Shaked⁵⁴ have pointed out, may impress the engineer without helping or educating him.

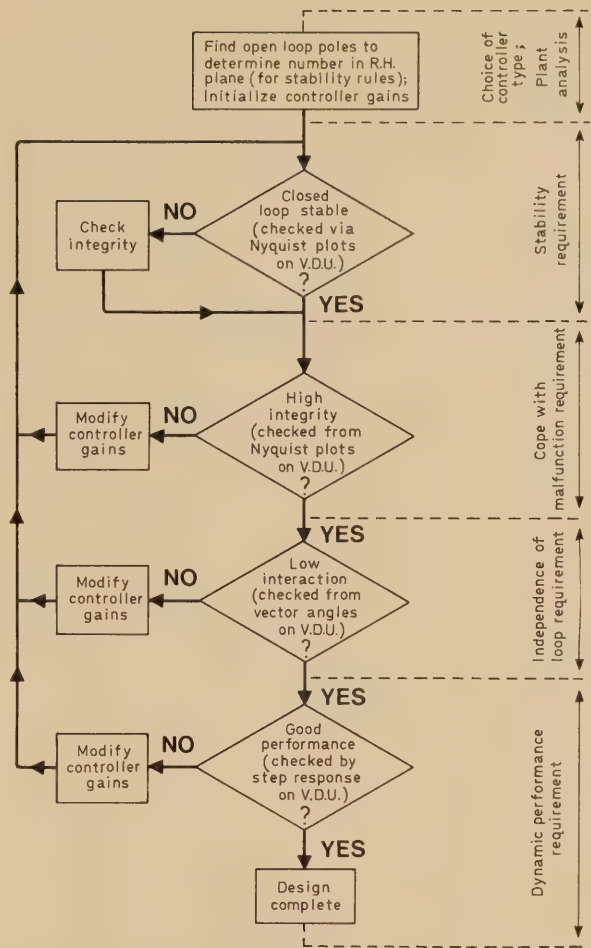


Fig. 1. Flow diagram of interactive computer-aided design of multi-variable control system via characteristic locus method.⁵⁸

Bringing the Two Sides Together

For some industrial control processes with a large number of variables in a network of interconnected loops, individual control loops may not in themselves significantly improve plant productivity, and an integrated control strategy for the complete system is required.⁵⁵ Notwithstanding the objections of reference 54, matrix-based methods are likely to find application.⁵⁶⁻⁵⁹ One design technique for such a multivariable system is conveniently summarized in flow diagram form in Fig. 1.

Having dealt with the multivariable case, we are then left with many control problems in which the present author feels a solution would be more readily identified by judicious modification of classical techniques via the inclusion of general guidelines observable from modern control theory. Hopefully, such developments will then lead to optimum designs without discarding known techniques and performance data, and will also result in a rational design approach, rather than trial and error which has epitomized so much of the classical work; not that there is anything philosophically wrong with 'trial and error' methods, the trouble is to bring design by different designers to the same standard, and to educate the next generation.

As an example, let us consider the design of a single input, single output system to achieve a given speed of response. Actually, it is really the design of a multi-input system, of which only one input is the ‘message’, in the presence of plant uncertainties and non-linearities as shown in block diagram form in Fig. 2(a). An infinite number of choices of $T(s)$, beyond the conception of the designer, are possible, even when the maximum step overshoot is constrained.⁶⁰ The unsuspecting user of classical control techniques may choose the first satisfactory $T(s)$ to appear, not realizing the troubles that may lie in wait. Standard forms based on integral criteria related to the step response may be used as a guide to selecting one response from another,⁶¹ and certainly permits the selection of a faster system for the same phase margin,⁶² as shown in Fig. 2(a). Assuming that a linear control law is required, how do we select $T(s)$ so that saturation at the plant input is a minimum? Modern control theory provides the answer here by minimizing the quadratic performance index $\int_0^\infty [\theta^2 + \lambda^2 \theta_p^2] dt$, integrated for a step excitation θ_i , where θ is the system error and θ_p is the plant input excitation.⁶³ For a large step in θ_i , the advantage in choosing the ‘optimum’ linear design is shown in Fig. 2(c). Chang’s original solution

was based on the root square locus technique, Leake⁶⁴ then showed that the same solution can be obtained directly from the return difference Bode plot by matching the dominant part of $T(s)$ to the effective plant transfer function over the frequency range of interest. Tustin⁶⁵ had pointed out that the practical problem was not saturation due to the step excitation, but high frequency noise superimposed on the ‘message’. It has been subsequently shown that the optimum linear design based on the step response integrals in the quadratic performance index is equivalent to minimizing high frequency plant excitation,⁶⁶ and, furthermore, the important factor is *matching the dominant $T(s)$ to the plant nominal $P(s)$ over the frequency range of interest*, and not in the exact choice of $T(s)$, as shown in Fig. 2(d). Sensitivity and load disturbance rejection requirements must be met by the correct choice of *structure*; as shown in Figs 2(e) and 2(f) respectively $T(s)$ choice makes little difference.

Tracking requirements are met by adding low-frequency lag networks, and additional noise rejection achieved by adding extra high-frequency lag networks well beyond bandwidth. This approach may be summarized in flow diagram form as shown in Fig. 3, and has already been automated successfully.⁶⁷

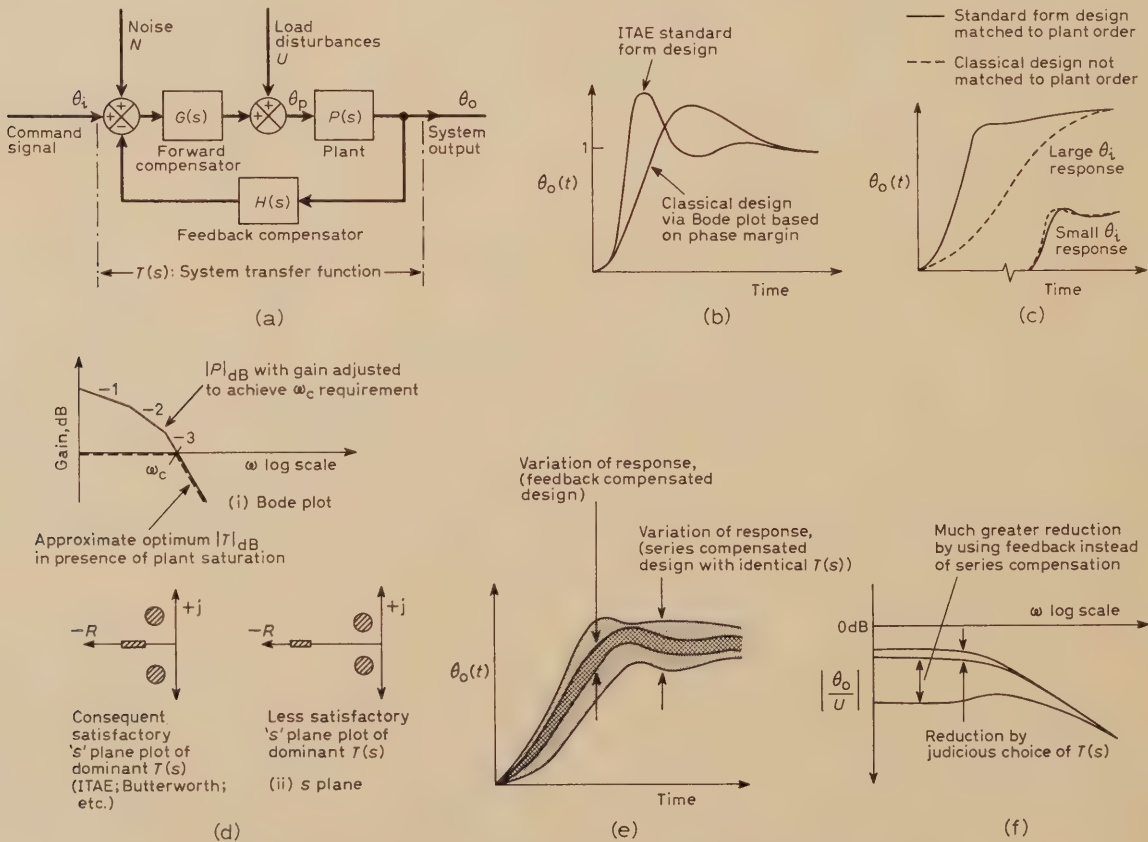


Fig. 2. Meeting various performance criteria in multi-input, single-output systems.

- (a) Terminology for multi-input, single-output system.
- (b) Improvement in step response via standard form design.
- (c) Improvement in presence of plant saturation.
- (d) Matching the dominant $T(s)$ to the plant $P(s)$ over the relevant frequency range.
- (e) Monte Carlo study showing benefit of using feedback compensation in presence of variation in plant dynamics.
- (f) Reducing the effect of load disturbances.

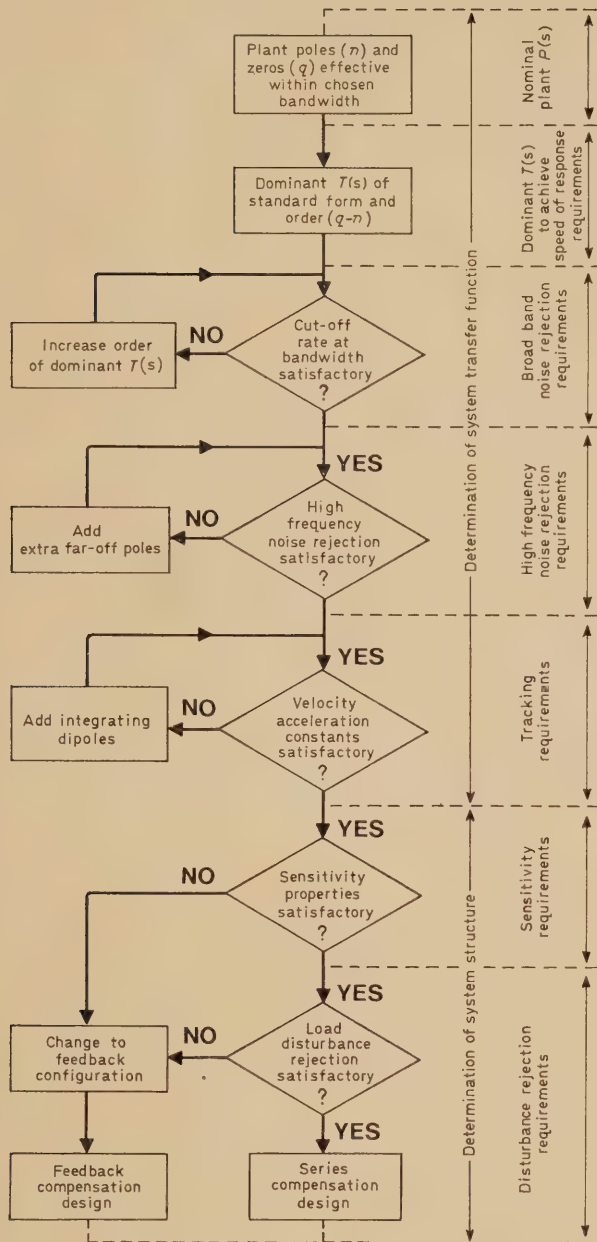


Fig. 3. Flow diagram of design of optimum system with saturating plant via transfer function techniques.

How Universal is Design?

If it is possible to rationalize design as shown in Figs. 2 and 4, it should be possible to identify some general characteristics of systems already in existence. This is indeed so, for example, with tracking systems, which are of particular interest to the author. In Fig. 4, the coefficient plane models for describing dynamic error performance are shown for a world-wide selection of such systems. It can be seen that all models lie within a relatively small region of the coefficient plane, in which also lie the models corresponding to a number of standard forms.⁶¹ The systems shown are generally of much higher order than third, but the coefficient plane models are adequate descriptions of the dynamic response.⁶⁸

Where does Undergraduate Education go from here?

Readers who have stayed the course will have realized that control engineering is currently controversial, rapidly changing, and universal in application. They may also be glad that I am returning to the original thesis of this essay; how should we educate? This question must be answered in the light of certain political pressures, quite apart from the fact that only a few percent of graduates can hope to become professional control specialists. The two political factors are (i) the pressure to reduce higher education unit costs, already a fact in both USA⁶⁹ and UK,⁷⁰ and (ii) provision of multi-disciplinary courses to make better use of manpower entering universities qualified only in arts-based subjects.⁷¹ I suggest the answer lies in the realization that many disciplines and professions require the capability to plan, communicate, model, predict, control, and implement, and since these capabilities can be taught via control engineering, it does resemble the teaching of Latin to pupils as a thought-provoking, orderly discipline. The important teaching principles therefore appear as follows:

- The use of block diagram notation to show cause and effect in physical, human, and economic systems. In non-physical systems the identification of variables and operators may be a profound problem.
- In all systems there is a message to be transmitted and noise to be rejected. There is an art in selecting the best trade-off in a given situation.
- Identical transfer functions have identical behaviour to the same inputs, hence we can solve many problems by analogy, using results displayed as standard responses.

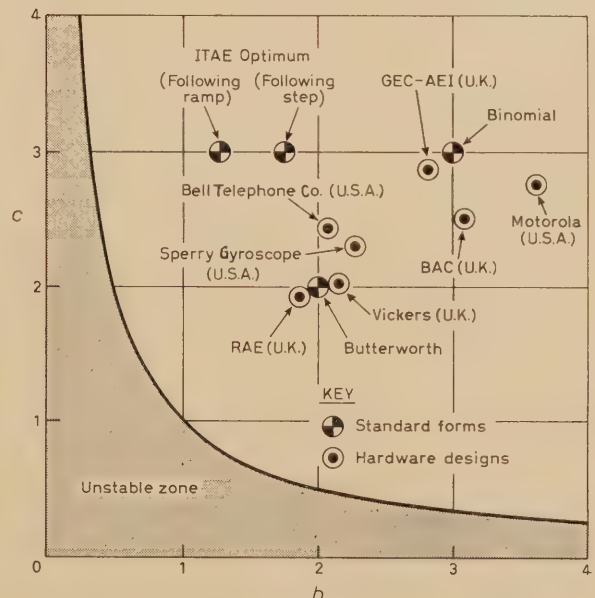


Fig. 4. The wheel is rediscovered! (or how good designers of tracking systems end up with similar coefficient plane models).

$$\text{Coefficient plane model: } T(s) \approx \frac{1 + c(s/\omega_0)}{1 + c(s/\omega_0) + b(s/\omega_0)^2 + (s/\omega_0)^3}$$

- (d) In specifying the performance of any system element, the specification must be related to the goals of the total system. This principle can be vividly illustrated by pointing out the deleterious effects of unwanted instrumentation lags on the stability of closed loop systems.
- (e) Judicious assumptions can reduce many systems to a size which can be handled without losing sight of the important features which constrain the system. At the feasibility study level, this skill is of paramount importance.
- (f) Feedback is used to correct drift, reduce the effect of unwanted signals, and to control the plant despite uncertainties in the plant dynamics, and is not necessary simply to shape input/output relationships.
- (g) Computer solution of dynamic problems is often most conveniently tackled using general programmes based on numerical integration techniques, rather than by implementing hand techniques (e.g. CSMP, etc.) convenient for written examinations.
- (h) The necessity to validate mathematical models of physical systems without unreasonable disturbance to the system (this is as important in economic and biomedical systems as hardware systems).
- (i) When operating data is sampled at discrete intervals, the sampling rate chosen has a direct effect on the clarity of the message (e.g. aliasing), and on system control.
- (j) Minor loop feedback greatly reduces system sensitivity to plant changes so why not provide suitable access? (This is as important in accountancy as in servos.)
- (k) At all times to avoid confusion between techniques and fundamental principles.

Acknowledgments

To all those contributors to knowledge who will not complain because they are omitted from the list of references in order to reduce it to a handleable size, thank you! Any review of this nature must inevitably be biased (but hopefully not prejudiced). I am grateful to Dr. F. Fallside of the Control Engineering Group, University of Cambridge, for keeping the bias within tolerable bounds!

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The Foundations of Computer Engineering

This is an edited report of a discussion on a summer evening between Mr. Michael Woodger of the Computer Science Division of the National Physical Laboratory, who was closely involved in the formative days of electronic computers, and Dr. J. R. Parks and Professor Douglas Lewin.

Douglas Lewin: Michael, in a recent issue of *The Radio and Electronic Engineer* a number of papers were presented commemorating the twenty-fifth anniversary of the stored program computer.¹ In the special edition of our Journal to mark our Golden Jubilee we thought it impossible to exclude computers and computing but would now like to take a broader view of their history. Is it possible to identify what, in your view, have been the major achievements in computers, in other words, what constitute the important breakthroughs in computer engineering from the hardware and software viewpoints?

Michael Woodger: Well, the first breakthrough was the ability to switch signals at electronic rather than electro-mechanical speeds, this made *ENIAC* work that much faster than the Harvard Mark 1. As a consequence of this increase in speed it became essential to have the program held in a form that could be modified and executed at full speed in the machine, in contrast to the externally plugged program sequences employed by *ENIAC*.

John Parks: This is the basic stored program computer concept which stores the program and the data on which it works in an electronic form so that they can both be manipulated and altered under program control.

M.W.: Yes, but that's not really the breakthrough, simply a consequence of the increase in speed.

D.L.: Von Neumann is often quoted as the originator of the stored-program concept—is that true?

M.W.: No, it isn't! The notion of the stored program is central to Turing's paper on the Universal Computing Machine published in 1936.² This paper was concerned with the principles of computation, in complete abstraction from any machine to actually carry it out. Turing postulated a device, the Turing machine, which could

be in state a, b, or c . . . as many as required. The device had a tape memory: it could either read from the tape, move left or right, or write something onto the tape. This tape is divided into a finite number of pieces, squares on each of which there may be a character, one of a finite set of characters. So you had a device which had a finite number of possibilities, and what corresponded to a program followed from the requirements of the order code. Depending on the state the machine was in and what was being read from the tape, two things would be completely determined:

(1) Its action—step along the tape left or right, erasing the symbol or printing a new symbol, and (2) the state which it changed to next. There you have an order code, and a stored program in the sense that you have a machine which could read off a tape a coded representation of another machine and do what that machine would have done had you had one. In other words it was a completely universal machine description interpreter. The fact that the storage was printed on the tape was no different from the fact that nowadays the storage is on serial media. For Turing the input, output and storage medium was one and the same.

Now Von Neumann must have known about this work because he was at the Princeton Institute for Advanced Studies in 1936 at the same time as Turing. This view is supported by Donald Davies of NPL who in his introductory foreword to a reprint of Turing's original proposal to build a computer at NPL³ made the following comments:

'Probably few of the early pioneers had read the remarkable paper (Turing's) but without doubt one man knew it and understood fully its significance—John Von Neumann. His comments to Eckert and Mauchly when he first saw *ENIAC*, and afterwards his own work with Goldstine, led to the flowering of the stored program computer in the USA, while in Britain several influences were at work and one influence was Turing himself.'

Donald Davies goes on to say that the original paper had an appendix dated August 1936 at Princeton University and it seems almost inevitable that Von Neumann knew about the work. Thus it was that, when he saw *ENIAC*, Von Neumann immediately suggested using the 'function switches', so called, to set up a program rapidly instead of the laborious plugging of cables that was part of the original design.

D.L.: That is very interesting, but it differs from the view put forward by Goldstine in his book⁴ that Von Neumann was the originator of the stored program concept. Have you read Goldstine's book?

M.W.: Indeed I have read it, there are one or two points which I would question, but most of it is correct. What

Mr. Michael Woodger in 1946 joined the team that built the pilot ACE at the National Physical Laboratory as Turing's first full-time assistant. Since that time he has developed and exploited interpretive systems for matrix calculation and compilers for Autocode and ALGOL 60; he is co-author of 'ALGOL 60'. He headed the Programming Research Group in the Computer Science Division of NPL in 1965 and now is a leading member of the Distributed Database Group.

Dr. John Parks (Member 1970, Graduate 1957) was with the Computer Science Division and its predecessors at NPL from 1951 to 1974, latterly as leader of a group working on pattern recognition. He is now concerned with the Advanced Instrumentation Project in the Control Systems and Electronics Division of the Department of Industry. He is a member of the Institution's Papers Committee.

Professor Douglas Lewin (Fellow 1974, Member 1960) is at Brunel University. (See p. 627 of this issue.)

I did find about Goldstine's book is that it reveals his attitude to sources that he has no detailed information on. Namely he treats them rather casually, and I feel that knowing some of the British background one is less inclined to attach great significance to other events which he describes that one doesn't know about at first hand. What I got most from Goldstine was the atmosphere of the team he was engaged with and the chronological order and context of various actions of which I had already been aware. That I found most valuable, I don't know where else you would have got it. Unfortunately Goldstine didn't include the key things about Von Neumann and stored program computers. I think Randell's book⁵ has got pretty well all that is necessary—all the key things are there.

J.P.: It is in effect a definitive record from an international point of view?

D.L.: That's right.

M.W.: If I may add another point, and that is the link between Turing's original work and micro-coding, or indeed wired-in instruction code. The Turing machine was described by a sort of fixed program which defined the behaviour of the machine in its various possible states. This table was fixed, the Turing machine could never alter its own table which was inserted eternally and rigidly in the machine. Now what else are micro-orders in a modern computer but a sort of fixed program?

What you don't have in a Turing machine is the idea of an address for referring to cells on the tape. The notion of a cell (in the tape) containing an address is not there, although used in all the original 'physical' programmed computers.

J.P.: Going back to the first stored program computers, very little has been published about what went on during the Second World War. Such work is not generally known about.

M.W.: Davies commented that 'Turing did secret work during the second world war which brought him into contact with digital electronics. He also met J. R. Womersley (later the first Superintendent of the Maths Division at NPL) and they talked about the possibilities of building fast computers.'

D.L.: Brian Randell is the principal exposé of the work that went on during that period.

M.W.: Randell has spoken to many of the people that worked with Turing during the war, particularly Donald Michie.

P.: Now where has that got us? Turing seems to have provided the seminal ideas with Von Neumann, carrying the metaphor a bit too far, being the midwife.

M.W.: John Von Neumann was such an immensely able and influential mathematician that he caused attention to be brought to things which otherwise would not have been supported as much as they were.

D.L.: I would like to move on now to the next major breakthrough.

M.W.: Machine-coding is pretty rare these days, nearly everybody uses an artificial source language not directly

related to the machine or the code. In this case there has not been a single breakthrough but instead there has been a steady and continual dying away of actual machine code programming and now it is almost unheard of.

J.P.: Where did that begin?

M.W.: The first idea of having a general formula which you could evaluate and get the answer, calculating arithmetic expressions as we now call it, goes back to Heinz Rutishauser of Zürich in 1951.⁶ He also made a translator, a very crude one which worked on the Swiss machine *ERMETH* in Zürich in 1958. Rutishauser was one of the grand old men and one of the originators of the ALGOL activities.

D.L.: But what about the breakthrough?

M.W.: Oh well, that again was rather like Turing's work, in that he saw how you could do it irrespective of the machine. He was helped very much in the design of the translator by his collaborator Corrado Böhm, who has been inadequately recognized in the literature. Böhm and Jacopini⁷ showed that any flow-diagram can be constructed in terms of three basic, one-in/one-out, forms: sequential execution with one action after another, the conditional branch where you did one thing or another according to a certain condition which you evaluate and then the flow resumed from either branch to a single exit, and the third form known as the 'while-do'. The 'while-do' has a condition and a statement—you test the condition, if it's true it does the statement and then it comes round again in a loop, tests the condition again and goes on doing that until the condition fails. As soon as the condition fails it quits and that is your exit.†

Now those three forms, sequencing, conditional branch, and infinite loop and a test, were shown by Böhm and Jacopini to be adequate for all flow-diagrams. I don't call that a particular breakthrough but it is one of the origins of top-down program design in which the programmer's broad intention is elaborated in increasing detail through several controlled stages of decreasing abstraction. This is structured programming which is nowadays an extremely successful and wide-spread technique.

J.P.: Is there then a parallel here between Rutishauser and Turing, with Böhm developing Rutishauser's

† The three basic forms can be illustrated in simple pieces of program.

(a) Sequential operations $A := 1;$
 $B := 2;$
 $C := 3;$
 $D := B + C + 1;$
 $E := A + B + C;$
 etc.

(b) Conditional branch
 if (condition) *then* (sequence of actions) *else* (some other sequence of actions),
 e.g. *if* $A > 0$ *then* $B := 1$ *else* $B := 0;$

(c) 'While do'
 while (condition) *do* (some sequence of actions),
 e.g. *while* $A > B$ *do* $A := A - 1;$
 (which is a very crude way of ensuring that variable A is set to a value equal to or less than variable B).

original thoughts as Von Neumann developed Turing's? *M.W.:* I am saying that Böhm worked with Rutishauser and never got much credit either then or since and right the way through he has been influencing programming techniques. I would also say that you cannot point to a single individual and say he had the most effect on programming language development. Nowadays Dijkstra has tremendous influence and effect but his work has been on the consideration of many processors working together and how to enable them to cooperate—loosely coupled cooperating processes and his work will become more significant as multi-processor configurations become more used. This is a pointer to the future.

Perhaps we should take a look in another direction. Now we are talking about the construction of computer systems, aren't we? Well, I do think that the development of an operating system which could handle several jobs as if, from an individual user's point of view, they were simultaneous—that is, 'time-sharing'—is a breakthrough. Time-sharing was the work of the Massachusetts Institute of Technology around 1961.⁸

J.P.: This is what turned itself into Project Mac and so on.

M.W.: Yes, Project Mac indeed, CTSS was the name—compatible time-sharing system. CTSS was the signal which alerted all other computer users to this possibility and again we haven't looked back since.

Yes, I must say, I declare it to be a breakthrough, undoubtedly a breakthrough! The principle of time-sharing, whether or not a single processor is managing it, or whether you have more processors is not really the point. The point is that many individuals, each with his own task, can be using one computer system at the same time.

D.L.: In a sense that really was the 'modern' breakthrough.

M.W.: Yes, that one was pretty late, and was rather a programming one.

Let's think more about construction and ask ourselves what it is the magnetic core contributed?

J.P.: It replaced serial delay lines and gave true random access storage.

D.L.: It considerably eased our programming problems because there is no longer any need for optimum programming.

J.P.: Optimum programming disappeared overnight.

M.W.: The fact that it was no longer worth while sequencing a program, that you didn't get any advantage if you wrote your program to access the store in a sequential order, that was a revolution! So first, we have been freed from the constraint of timing, and second, from the constraint of sequential processing, the order in which things happen to be in the machine suddenly became irrelevant as regards fast store. To get away from the need to consider the hierarchy of stores of differing speed characteristics and differing modes of access, that is a desire which has been with us all these years and has never come to fruition, we still have to take account of stores of different sizes which is an absolute pest to the programmer and everyone else.

I'll tell you what another breakthrough is, it is not always considered so but it is my opinion, and that's the visual display unit. Once you have accessed a computer through a v.d.u. you have a speed-up in response, as opposed to a teletype, which alters the things you can reasonably expect to do within human response times. In a way it means that there are things which you can do now as a human being which you just could not do before. To wait while the teletype types out a framefull of stuff leaves you in a condition where you cannot remember what you had in mind to do at the moment you started. Again, this is a technique which is only slowly being brought into regular use, on account of the expense of v.d.u.s, but more and more people are using them for programming and interacting with computers generally.

J.P.: They are pretty well standardized for interaction with large data-banks and particularly text editing.

M.W.: Yes, an editor with a teletype would be almost unheard of wouldn't it? O.K., I think we have got another breakthrough!

D.L.: I think we ought to consider whether the transistor and the integrated circuit are breakthroughs.

M.W.: We are still on our way through to the benefits of integrated circuits, the promise of very high reliability has not yet been fulfilled.

D.L.: I would not totally agree with that. If you consider the first generation computers, the valved machines, you were lucky to get a couple of hours mean-time between failures.

M.W.: That's so. On the Pilot ACE, I have a note in my diary—September 1950—when it first went half an hour without error—it was a fantastic event!

J.P.: Enormously increased reliability has followed through from the use of solid-state devices. There are now more active devices in a pocket calculator than in many of the early computers. Physical movement of the early machines was virtually unheard of after initial commissioning and now we carry them around in our pockets!

D.L.: I think this is a major point, because if we had not achieved significant reliability people would not have been so enthusiastic about the computer.

M.W.: Each time they switched on the ENIAC on the average 35 valves failed. You could leave the equipment switched on of course, but 10 000 hours was the upper limit for a typical valve, say the 6J6. I know, having numbered every 6J6 on the Pilot ACE!

D.L.: This is very interesting. One of the basic problems that industry has generally is reliability—they want secure systems. Now the way we are tackling this at the moment is by using redundant structures, by attempting to perform testing and diagnostics in operation and so on, because we have always assumed that we are not going to get this ultimate reliability.

M.W.: If nothing can go wrong with the chip then you are well away. If it passes the original acceptance then it will stay like that for ever and a day—an automaton

whose performance is guaranteed to remain rigidly fixed in time.

J.P.: An ideal, but unfortunately other things limit the integrity of any system. The reliability of l.s.i. chips is generally an order of magnitude greater than their encapsulation and the connexions between them and the outside world. However, we are already seeing systems which regularly test themselves as part of their programmed operation.

D.L.: The effect of getting more and more devices on a chip, coupled with increased reliability and self-diagnostics, will hopefully mean that we shall be able to replace a defective chip upon instruction by the system itself!

M.W.: I see, it is not so much self-diagnostic as diagnostics of another part of the chip, isn't that right?

D.L.: Yes indeed. Now what about micro-programming, wouldn't you call that a breakthrough?

M.W.: Micro-programming was proposed by Wilkes and Stringer in 1953⁹ but it had always been regarded as a very natural approach, in fact an earlier paper by Wilkes in 1951 was called 'The best way to design an automatic calculating machine'.¹⁰

D.L.: For me, Wilkes said everything about micro-programming in that first paper, and all the current micro-programmed machines are directly descended from that work. In fact the concept of the control store and dynamic micro-programming also dates from that time—the STC Stantec *Zebra* machine, described in 1951, was dynamically micro-programmed.

M.W.: But I don't see how it can be a breakthrough if it was proposed at the Manchester Conference in 1951, implemented as the *EDSAC 2* and then people carry on quite happily without reference to it. In what sense is it a breakthrough?

D.L.: As an important conceptual way of thinking about computer design, which has allowed the hardware to appear more closely to approach the user's preferred instruction set and opened up the idea of emulation.

M.W.: If users had such fantastic intelligence that they knew what sort of order sets they would sooner have than the one they have got then they would be capable of saying 'I want this sequence of things, etc.'. Now that sort of user doesn't occur! You can't even get users to say what they would sooner have in a sub-routine library, let alone what order-code.

I must confess what I was impressed by, and I have yet to see if it is practically significant, is the degree of flexibility offered by the Burroughs 1700 machine where it is explicitly understood that an operator may load a cassette with one sort of micro-code for a particular high-level language and in a matter of minutes may load a different one for another sort of processing. The efficiency and the patterns of primitive activities that are available in the two may be radically different.

D.L.: The thing I like about micro-programming is that it does open up the idea of hierarchically-layered computing systems.

M.W.: Yes, conceptually it is delightful and is one of the themes in structured programming.

D.L.: I think we have concluded that micro-programming is not quite so much of a breakthrough as I thought it was.

J.P.: Does the same go for pipelining?

M.W.: It is an elegant design with much the same sadly reduced impact on the utilization of computers. Similarly with the array processor—to make it economic you feel you have got to use it in a way that you are not constrained to with your present machines.

D.L.: Do you think there is any future in array processors except for rather specialist application?

M.W.: There are some important problems in weather prediction and nuclear fusion research which demand a fantastically fast array processor, but these are very special applications as you say.

J.P.: But doesn't that follow into finite element analysis in general?

M.W.: No, it doesn't, because in the two cases I mentioned you have a multi-dimensional space of objects, each behaving precisely the same way with regard to its neighbours and I am talking about the finite element representation for a continuous medium. Where you have a set of partial differential equations of three or more variables you are absolutely up against it. You really want them to go together—there is no sequencing at all—whereas in finite element analysis of civil engineering structures you don't essentially have a continuous medium. That is the point.

D.L.: Would it also be true to say that there are very difficult software problems? In the case of the two special applications you mentioned it is worthwhile solving these problems but for the more general sort of applications it would not be worthwhile tackling them.

M.W.: I think that the software problem is one that is intolerable only in attempting to cope with a broad spectrum of applications. It is unbearable in that case. Where you have a narrow field, with more money being put into it, and comparatively few programs to write you could actually afford to write them in machine-code. Software production problems are more significant the more widespread the applications and the greater the number of people required to cope with them.

D.L.: There is no future then in general-purpose array processors for solving a wide range of computational problems?

M.W.: Not a wide range, no. I would agree with that, but I would also point out that what I have just said really implies that high-level programming languages have less application for the special purpose array processor.

J.P.: Can we return to the question of reliability again but this time software reliability?

M.W.: I must declare my disbelief in the possibility of software reliability. I don't believe in it. Unreliability in software is traceable to two things, finger trouble—which is one result of the unnaturalness of input devices, sheer blunders in other words, and mental trouble—which means you cannot quite grasp what you have to do and you make a mistake. Now that latter

aspect is improved by taking the thrill out of programming. Dijkstra once said programmers feel they are enjoying their work most when it is risky, when they are only just managing to understand, or even perhaps don't quite understand, what they are doing. What we want is a more pedestrian sort of programming in which you never at any moment attend to more than your mind can naturally grasp. You separate concerns so that you can attend to one thing, get it right, write it down, trust it and then having settled that direct your attention to another concern.

D.L.: This is the engineering approach to designing complex logic systems.

M.W.: This is now the engineering approach to programming, and I take the view that Dijkstra and I thought of this together. He published his paper¹¹ on 'Structured programming' and I reacted to this and produced a paper on 'Semantic levels in programming' for the IFIP Congress in 1971.¹²

D.L.: In other words, if you are designing a complex logic system the first thing you do is to draw a system block diagram which is not concerned with the physical contents of the blocks but rather with information flow between blocks and their effect on the information passing through them. It is a natural consequence of the complexity of the problem that the designer has to break it down in this way.

M.W.: Programmers are forced to break a problem down in this way too but they have not recognized this fact until relatively recently. They have muddled along thinking they are clever enough to fight through without imposing precise structure in their programs.

D.L.: So the way to more reliable software would be to adopt a modular approach where you develop software modules which have been tested and work, but perhaps not as efficiently as when written in a clever fashion. These well-trying modules are then connected together to give you your complete program. But there is still a problem and that is how do you specify what you want to do at the conceptual level.

M.W.: Well, this is where the 'virtual machine' idea comes in. There you do have modules but the modules are not simply what happens to be a nice convenient chunk. The modules have a life of their own in the sense that you work at one level where the effect of the module can be understood in a certain domain independent of the means of its achievement. Now if you can break down the programming of the task and find modules so that you can understand the overall program in terms of these modules, they would ideally form a hierarchy. The modules at the topmost level represent relatively substantial pieces of activity, but whose effect can be named and conceived and understood as some sort of act, like 'prepare a matrix and find its eigenvalues'. At the top level activities would naturally group together and then when you came to dealing with more detail you would have lower level modules.

I have constructed quite elaborate programs doing my best to follow this principle and in practice have never got more than a few levels. The point I am making about

modules is that the modules you choose are determined by the problem you are trying to solve, not by any prescribed technique. The separation of concerns is the key lesson of structured programming techniques. This principle goes a long way and we are only at the beginning of it. If you think that is a breakthrough I am on your side but it has not happened yet. That is to say, although the idea is a gleam in some people's eyes, although Dijkstra constructed the operating system for the Electrológica X8 based upon the clear separation of levels of program detail and first showed it was a workable and delightful tool, the X8 has gone obsolete and as far as I know no one has done any work on it since, so we have not learned the lesson as a community.

D.L.: I suggest it as a breakthrough, one which is going to lead to large changes in the future, if we are thinking in terms of the past to the present, this is the present.

J.P.: Having arrived at the present, this would be a neat point at which to end this conversation.

M.W.: I could go on for ages reminiscing. Sometimes I feel the questions left unanswered years ago should really be taken up again and another look taken at them. . .

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Electronics and Nuclear Power

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Against the background of the development of nuclear power stations, radiation measurement, electrical interference reduction, reactor control and increasingly sophisticated techniques using computers and statistical methods, the achievement of electronic equipment which can be 'fitted and forgotten' is now becoming a reality.

The founder members of the Institution would be surprised if they could return today, after an interval of nearly fifty years, to see the range of applications for electronic devices and electronic equipment. There is hardly an area of contemporary activity that does not depend in some way or another on the use of electronics. Large new industries now exist, dependent upon electronics, that could not have been predicted fifty years ago. Nuclear power is probably a most important example. At the present time it is the only practical means of supplementing our dwindling reserves of fossil fuel. For some years to come this must mean the use of the energy from the fission of the heavy elements but in the longer term the energy could come from the fusion of the lighter elements.

The Initial Research Phase

The history of nuclear power shows that it has always been wholly dependent on electronics. It is not an exaggeration to say that throughout the period of research from about 1930 to about 1950 that led to the proving of the possibilities of practical power generation, the pace of the research was almost wholly dictated by the pace of the development of new electronic techniques. Every new advance in electronics enabled an experiment to be performed that was impossible before, and each new experiment provided new data or more accurate data that built up the background against which practical

applications began to emerge with increasing certainty. This period covered the emergence of the Geiger-Müller counter from the university laboratory where 'green fingers' seemed to be necessary to produce a satisfactory device, to its appearance on production lines of smaller companies with a reasonably high production yield. Following the discovery by Trost¹ in 1937 of the self-quenching mechanism produced by using a small quantity of polyatomic gas, the Geiger-Müller counter was used in larger quantities because it needs only fairly simple electronics, mainly in the form of scalars. The proportional counter provides a pulse whose size is dependent upon the amount of ionization produced by the radiation particle thereby enabling a distinction to be made between radiation from different sources. It needs some pulse amplification and here considerable development² was necessary to produce amplifiers with the desired gain, gain stability and low noise level. The mean current ionization chamber, which is used in a way which integrates the ionization from individual particles into a mean current, demanded the development of 'electrometer' type techniques to measure with precision the very small current involved.^{3,4}

Since about 1950 these techniques for measuring radiation have been supplemented by the scintillation counter, where the radiation produces flashes of light that are observed with a photomultiplier, and provided the first reliable device for measuring gamma-ray energies.⁵ A variety of semiconductor radiation detectors have been developed⁶—notable amongst which are the lithium drifted germanium devices which, when used at liquid nitrogen temperatures, enable gamma-ray energies to be measured with extraordinary precision.⁷ Very recently the thermoluminescent dosimeter^{8,9} has emerged as a very satisfactory replacement for the film-badge in monitoring the radiation received by individuals. Here the energy deposited by the radiation is stored in material such as crystals of lithium fluoride and is later released as light by a carefully controlled program of heating.

The experimental work of these early phases of the development of nuclear energy was dominated by radiation measurements largely because the emphasis was on establishing the physical processes governing the interaction between radiation and matter. Such experimental work was only feasible using electronic techniques.

The First Nuclear Reactor

The first major milestone in the development of nuclear power was the achievement of a self-sustaining neutron

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chain reaction.¹⁰ This occurred in Chicago on 2nd December 1942 under the stands of a baseball ground. It was part of a very intensive military programme. The control and instrumentation of this first pile was extraordinarily simple by present day standards; in fact, I sometimes wonder what a Licensing Authority would say about them today. The instruments were almost exclusively those measuring radiation. A few boron trifluoride proportional counters measuring neutron flux levels were used to operate recording instruments and automatic safety controls. The latter included two safety rods and rather surprisingly an automatic control rod, which was described as being 'intended to keep the intensity of the reaction at a constant level'. Many reactors were built subsequently where an automatic control system was added later as if it were an outstanding technical innovation.

Under the spur of the military programme very large reactors to produce plutonium were rapidly built in the USA and Britain. In these plants the problems of getting rid of the heat in a safe way resulted in large quantities of instruments to measure temperatures and coolant flows at a large number of points in the plant. The quantities of such measurements completely dwarfed the quantity of neutron flux measurements but because they used well-established techniques they were rarely mentioned in the literature. The myth thus grew that the main instruments in a nuclear power plant are those concerned with neutron flux.

Electricity Generating Plants

A lot of us were quite unhappy to see the large quantities of heat produced by these plutonium-producing reactors going to waste. A conference was held at Harwell in September 1950 to explore the feasibility of producing electricity on a commercial basis using nuclear reactors. In 1952 the British Government authorized the building of the first Calder Hall plant¹² to produce both plutonium for the military programme and electrical power. This fed about 35 MW to the National Grid system on 17th October 1956 and became the world's first regular power producing nuclear reactor.

This was followed quite quickly by demonstration power plants of a whole variety of types and in a number of countries, principally the USA, USSR, Britain,¹³ France and Canada. This period may be described as one of demonstrating technical feasibility with the emphasis on technical eminence but from about 1962 onwards the main objective turned to the achievement of low capital cost. The argument was that in spite of the running costs of a nuclear power station being very low in comparison with a coal-fired or oil-fired power station, it was necessary to reduce the capital cost in order that the overall generating cost could be made competitive with coal or oil. This led to the quest for high efficiency and high power ratings and quite extraordinary complications were introduced in order to achieve a few per cent more power output from a given design. Most countries who are building nuclear power stations today have now had experience of construction programmes being late and of unexpected technical

problems. Perhaps it is not unkind to say that most of these have stemmed from this urge to achieve the lowest possible capital cost. Today with a five-fold increase in the cost of oil together with an inflationary economy which emphasizes the value of low running costs in

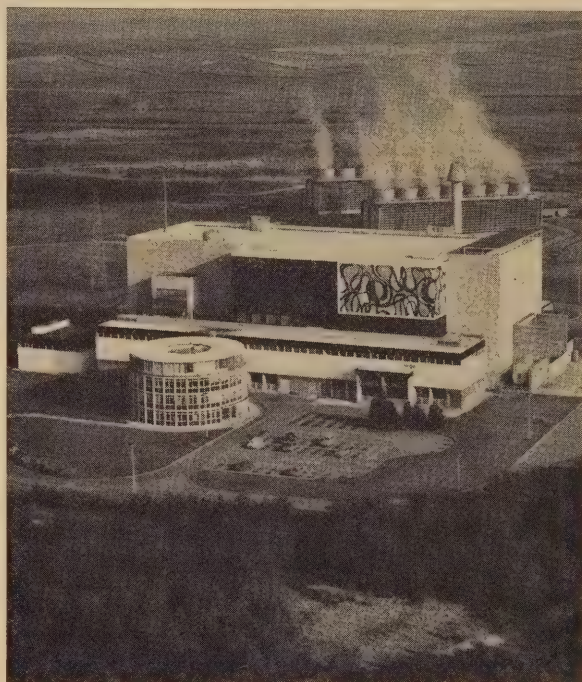


Fig. 1. The Steam Generating Heavy Water Reactor (SGHWR) power plant at Winfrith in Dorset. This first delivered electricity to the National Grid about Christmas 1967 and is the prototype of the plants now planned for installation in England and Scotland.

future years, the quest for low capital cost has substantially reduced. The emphasis is now on guaranteeing performance and meeting construction programme dates combined with low maintenance costs leading to a 'fit-and-forget' philosophy for the electronic equipment.

Systems Engineering

A modern power station is almost incredibly complicated, giving rise to considerable problems in the organization of installation and of maintenance. Modern electronic equipment using integrated circuits is about 1000 times more reliable than the valve equipments of 20 years ago. Considerably more electronic equipment can be used with even a reduction in the staff needed for maintenance. Many previously-used instruments particularly those for coolant pressure or coolant flow needed frequent mechanical adjustments *in situ*—often in positions that were almost inaccessible when the plant was running. These are rapidly being replaced by electronic types that need no mechanical adjustments and can be left for years without attention. This is one example of the types of development that are currently in progress in the field of the control and instrumentation of nuclear power plants. Nowadays far less effort is deployed on proving the feasibility of a particular new



Fig. 2. (top) Part of the Control Room of the SGHWR power plant at Winfrith.

(bottom) Almost the whole of the Control Room of the Prototype Fast Reactor now being run up to power at Dounreay in Scotland. Note the almost complete absence of panel meters and their substitution by cathode-ray tube displays. Although these are displaying information in alpha-numerical form, it is more normal for most of them to be in analogue or graphical form.

type of measurement technique, instead the majority of the effort is concentrated on making easier the installation, commissioning and maintenance aspects and on the interpretation of signals by the operator. The focus of attention has moved out of the laboratory into an industrial environment.

Electrical Interference

The recent developments display a much greater emphasis on systems engineering aspects. One very important area is concerned with electrical interference, which was frequently a source of trouble in nucleonic equipment for nuclear power plants. This is not surprising since the equipment often has to detect continuous currents of order 10^{-12} A or pulses less than 100 ns and a few hundred microvolts amplitude on sites where power circuits may carry kilovolts and kiloamperes. It is normal to design each measurement channel to be completely screened but in practice it is quite common to find, on installation, that cable screens are not properly bonded to plug shells or other almost obvious imperfections in screening occur. However, when cable lengths exceed about 50 feet the screening properties of the cables themselves can be the limiting factor. This is because most sources of interference—and switching surges are by far the most important—cause currents to flow to ground through the screening of the measuring equipment and it is this flow of current that causes signals to be generated that interfere with the measurements.¹⁴ Experience shows that these currents can be up to 100 mA at any frequency up to at least 100 MHz.

The screening quality of a coaxial cable is determined by its surface transfer impedance (Z_T) which is defined as the signal in volts generated between the centre conductor and its sheath for one ampere of current flowing in the sheath per metre length. A solid copper-sheathed mineral-insulated coaxial cable (e.g. the pyrotenax cable used in hot environments) can have a surface transfer impedance of about 20 m Ω at low frequencies improving rapidly above about 500 kHz because of skin effect to a figure of less than 1 $\mu\Omega$ above 20 MHz. A typical polythene coaxial cable with a single braided copper sheath has a similar value of Z_T at low frequencies but gets progressively worse above a few MHz because of its braided construction.

The superscreened cables¹⁵ which are now used extensively in the nuclear energy field are significantly better. The simplest superscreened cable uses a mu-metal tape wound between a pair of copper braids. A more sophisticated design uses a pair of mu-metal tapes and three copper braids. This has a Z_T of about 7 m Ω at 100 Hz falling rapidly to below 0.1 $\mu\Omega$ at all frequencies above 100 kHz. Thus it is more than 10^5 times better than a single braided cable at frequencies above about 100 kHz. Incidentally these superscreened cables are little more expensive than similar sized double braided cables and their use would be much cheaper than most applications to date for the relatively expensive fibre optic systems over distances of more than a few tens of metres. Also studies of the flow of these interference generating currents through the metalwork and wiring of electronic units has led to a complete revision of the

principles of their mechanical design. These are concerned with minimizing the generation of magnetic fields that can couple with the sensitive circuits within the unit. Combined with these advances involving the design of equipment there have been corresponding advances in the methods of measuring the sensitivity of complete installations to electrical interference and the diagnosis of the location and cause of unsatisfactory performance.^{16,17}

Safety and Availability

One of the more significant problems in the control and instrumentation of nuclear power plants has been the need to keep the plant running in the face of the failure of individual items of equipment that are not of major importance but to be quite certain that the plant will shut down when a potentially serious malfunction occurs. This led to special attention being paid to what is called the reactor safety system¹⁸ which is basically the logic network that takes the information from all the safety instruments and decides on the form of automatic protection to initiate. In the first ten years of reactor design, emphasis was placed on fail-safe techniques so that any failure caused the automatic shutdown. From the Calder Hall programme emerged the use of redundancy techniques whereby a number of instruments (initially usually three) was used to detect an unsafe situation and action was initiated when more than one indicated the unsafe state—the so-called 2-out-of-3 majority voting technique. This significantly reduced the spurious trip frequency but led to difficulties in detecting whether faults have developed in the redundant part of the logic system. Initially the logic systems used electromagnetic relays with the relays energized in the 'safe' state of the plant, but relays have a tendency to stay stuck and not move when they should. This inspired the development of dynamic logic techniques where continuous switching of solid-state electronic circuits indicated the safe state and cessation of switching initiated automatic shutdown.^{19,20} From this emerged pulse coding methods²¹ whereby instead of using the same uniform pulse-train into each of the three lines of a 2-out-of-3 system, a different pattern of pulses is fed into each

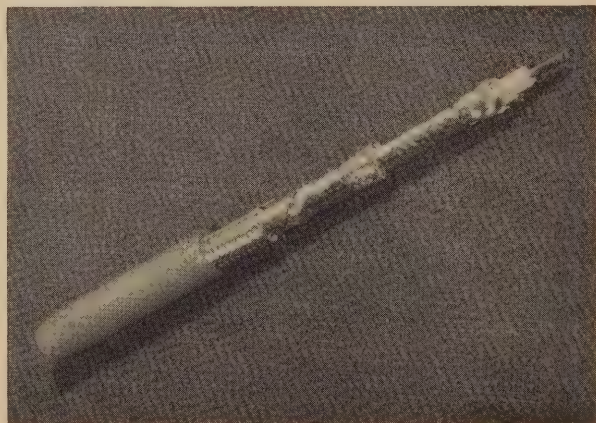


Fig. 3. A piece of superscreened cable showing the two layers of mu-metal tape wound between the three copper braids.

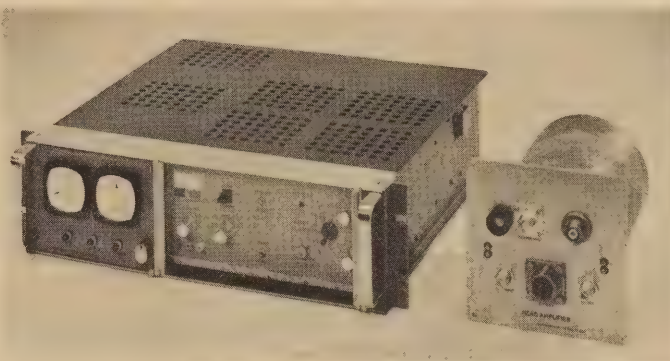
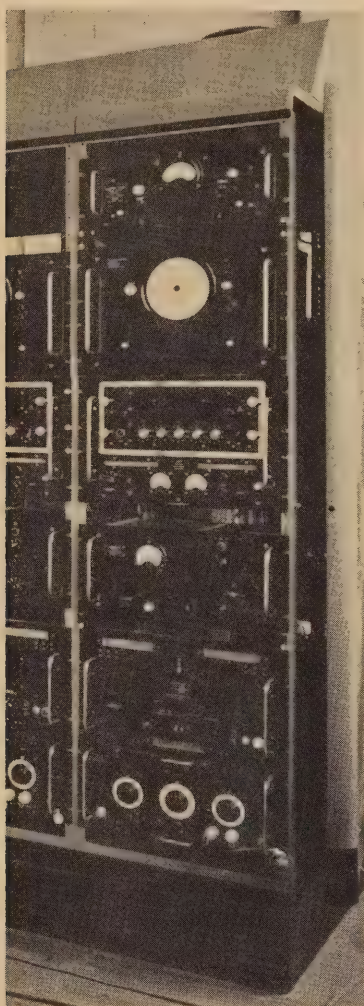


Fig. 4.

(a) (left) A pulse counting neutron flux channel using thermionic valves as used on nuclear reactors from about 1957 onwards.

(b) (above) A more recent pulse counting neutron flux channel using transistors and integrated circuits.

Resolving time	500 ns	50 ns
Maximum length of polythene cable between radiation detector and head amplifier	7 m	100 m
Power consumption	850 W	40 W
Mean time between failures	4 weeks	10 years

and the pattern of pulses at the output enables any fault in the system, including the logic array, to be diagnosed and located.²² This becomes particularly attractive using modern l.s.i. arrays using computers for the display to the operator and the analysis of fault patterns. Reliability studies indicate an improvement in reliability and spurious trip rate of many orders of magnitude compared to systems using relays.

Nuclear power plants have used computers²³ quite extensively from the early days. Initially they were used in a data logging and data presentation role to assimilate the vast quantity of data produced by the multitudinous instruments and to present the significant information in a readily understood way to the operator. Gradually more and more control loops were introduced into each system, and on recent plants such as the Prototype Fast Reactor (PFR) at Dounreay, most of the plant is controlled by the central computer²⁴ and relatively few instrument dials are visible to the operator; the relevant information is available to him on a number of cathode-ray tubes in alpha-numeric or analogue display form. These mammoth computer systems have worked very well but have presented formidable problems in achieving

the necessary continuity of function in the presence of equipment failure.²⁵ They have tended to use a pair of main-frame computers with an automatic change-over system.

It is almost inevitable that at some time the use of computer-like techniques will spread into the primary protection systems of nuclear power plants. Recent studies suggest that the use of a pair of standard main-frame computers is unlikely ever to reach the standard of reliability and safety required. A particularly difficult problem is the proving that no dangerous errors exist in the software. Current thoughts on high integrity computing lead to the concept of a number of microprocessors or minicomputers located at various parts of the plant, each performing almost dedicated functions with one or more central computers performing a supervisory and co-ordinating role, all of them linked together with a high performance communications network. The development of reactor safety logic techniques to improve their integrity highlighted the importance of the 'stuck' relay and one must question whether this phenomenon has its parallel in present-day computer methods and whether information movement within a computer should not use one or more complete cycles of switching of each logic element and possibly more than one path. Also the protection from unintentional operator corruption of vital programs concerned with primary safety need methods of much greater strength than those in current use today.

Recent Developments

Although the emphasis in developments has tended to move away from the radiation measurements, there has

been one development that is intriguing—the so-called Campbell technique for measuring neutron flux. It is called the Campbell system because it exploits a theorem on statistics published by N. R. Campbell in about 1910.²⁶ In a nuclear reactor the fission process must be controlled at all times²⁷ and in a nuclear power station the instantaneous fission power at shutdown may be 10^{-8} to 10^{-11} of that at full power. This means that the neutron flux level must be measured over the same range. At the lower power levels this is normally done by using a system where the pulse from each neutron causing an event in the radiation detector is amplified individually and the pulse repetition rate is a measure of the neutron flux. At higher power levels the mean current flowing in the radiation detector is a measure of the flux level. However, gamma rays will also cause a current to flow in the ionization chamber but such currents are not necessarily dependent upon the fission power at that time. In many applications such gamma background currents limit the range of powers over which an ionization chamber may be used. However, if we measure the fluctuations of the current²⁸ rather than the mean value, we find that the level of fluctuations is proportional to the square root of the power level, so that a device covering a range of 10^6 in reactor power level will need to measure a fluctuation signal level of only 10^3 , thus easing some of the electronics design problems. However, we also find that the system output is heavily weighted in favour of the larger pulses. In practice this can give about a 1000 times improvement in the discrimination between neutron pulses and the smaller pulses from gamma rays. The advantage can be of considerable significance in terms of the siting of neutron detectors, particularly in fast reactors where the saving in terms of the cost of the plant can be very considerable. However the technique involves a significant number of design optimization problems particularly in relation to its speed of response and noise level of its output. It can use the same radiation detector—in the form of a fission chamber—as a pulse counting system, thus allowing one penetration of the reactor containment to be used to monitor the entire range of neutron fluxes—with the obvious plant cost savings.

There are a number of other developments on the instrumentation side of nuclear power where the current state of knowledge of electronics must be extended by a significant amount to achieve success; these are principally concerned with the measurement and protection problems of the sodium-cooled fast reactors. However, electronics is already making a deep penetration into the design of the heavy electrical machines used in power generation. Solid-state electronics has fairly rapidly replaced the Ward-Leonard set for the control of large variable speed motors.²⁹ The reason is that motors using commutators have always presented a considerable maintenance penalty in the form of not only highly skilled manpower but also lost time. The solid-state electronic replacements are almost maintenance-free. For many years the control equipment for turbines was hydraulically operated but now many turbines have electrical control gear, which provides a wider range of choice of control parameters as well as reducing maintenance problems.

The Future

In the days of the thermionic valve, electronic equipment was treated as being clever and versatile but quite unreliable. In fact there was a frequently heard joke that at the first sign of trouble on a nuclear reactor the operator would immediately blame the instruments and not take the appropriate corrective action—and frequently he was justified. Quite quickly, with the advent of modern semiconductor equipment, the situation has dramatically reversed. Nowadays, electronic equipment is used in very much larger quantities, usually in fully redundant and self-monitoring systems and the reliability is so high that it is now quite rare for trouble to originate in the electronic parts of a system. Suspicion now falls immediately on mechanical items.

The versatility of electronics is already being exploited to ease the job of the operator in interpreting the significance of information being presented to him. To do this, the electronic engineer is being expected to understand a complete system and to devise equipment that performs tasks that previously exploited the intelligence of the operator, as well as his manual dexterity. At the present time it begins to look as if further progress in this direction may well have to follow along behind an expanding understanding of how human operators exploit their abilities.

The expanding use of machines in the modern world is already posing considerable problems in terms of the quantity and quality of staff necessary to keep them operating. In the field of nuclear power it is apparent that the reliability of modern electronic devices, even for heavy power equipment, is stimulating the development of systems using electronics in preference to equipment that wears out and thereby needs regular maintenance. Electronic equipment is beginning to be treated as equipment that you 'fit-and-forget'.

All these directions of development for the future are placing an increasing emphasis on what may be broadly termed systems engineering. The electronic engineer of the future must be not only a specialist in electronic equipment design, he will also be expected to understand in some depth the requirements of the application of his electronics.

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Ocean Technology

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Trends in oceanographic instrumentation over the past 10 years have included the adoption of digital methods, the use of submersibles, precise underwater position fixing and the use of satellites, the latter however being very restricted. The development effort on large data buoys is discussed, and some important recent developments in acoustic techniques are presented. The final section deals with outstanding problems in oceanographic instrumentation, in particular that of current measurement.

Introduction

The rapid development of exploration for and production of offshore oil and gas in recent years with the eyes of the world focused on our 'back-yard', has been the highlight of ocean technology, but research and development in other fields has also been progressing at a steadily increasing rate. The increasing draught of super-tankers and other very large cargo carriers has meant that channels previously considered to be 'deep' are now near the limiting depth for these vessels. This has raised various problems connected with surveying them, predicting how quickly features such as sand waves in them will change, and predicting the occurrence of negative surges due to meteorological effects which can significantly lower the level of the water below that of normal tides.¹ This is part of the justification for research into tides and surges, which also has major applications in other fields; the design and operation of the Thames Barrage and a possible tidal power scheme in the Severn Estuary, for example. Fisheries research has become if anything more important as the waters open to our fleets have become restricted and exploitation of fish stocks more intense. New fishing possibilities must be investigated, the conservation of stocks studied and methods for fishing farming developed. Marine pollution, and in particular the pollution of estuaries is of growing concern. There are subjects like coast erosion, siltation of harbours, and the effects of offshore sand and gravel extraction which involve studies of the movements of sediments. And last, but not least, pure research continues to provide the basic knowledge

to allow us to tackle tomorrow's problems in a more effective manner.

All these aspects involve electronics in one way or another. The sea needs to be explored, environmental parameters must be measured, the results analysed on digital computers, and ships and equipment must be guided, controlled and their performance monitored. Numerical models of the sea are built which make great demands on computer size and speed. It would take a book to do justice to the whole field, so I have selected a limited number of topics which seem to me to be of particular interest or importance with, needless to say, a bias towards those aspects with which I am familiar. A list of references for further reading is given and it seems appropriate for this essay to give this list a bias towards UK papers.

Trends in the last 10 years

The oceans tend to work comparatively slowly, which means that to study many phenomena instruments have to be left in position for several weeks, months, or sometimes years. This is reinforced by the difficulty and expense of emplacement and recovery: an ocean-going research ship costs between £2,000 and £3,000 per day to run, for example. Large pressure cases are expensive and difficult to handle: thus, the power supply which can be carried is limited. In these circumstances the availability of a wide variety of c.o.s.m.o.s. digital integrated circuits which run on almost literally flea-power has extended the range and even more the effectiveness of things which one can do in the sea. For example, crystal clocks have generally replaced mechanical clocks, and although power cannot usually be spared for thermostatic control of the crystal, this has allowed an improvement of at least two orders of magnitude in precision of timing as well as improved reliability. It has allowed the wider use of f.m. techniques with all the consequent advantages: although the primary sensor circuit has to be analogue, the rest of the processing and recording can be digital with effectively unlimited precision.² Precise frequencies can be generated by crystal oscillator/frequency divider methods for the carriers of long-range (and therefore long pulse/narrow band) acoustic beacons.³ Digital techniques have an important advantage from the point of view of the control of data quality, since modern digital circuits usually either work correctly or are obviously faulty. This trend to digital circuits has been part of a general push towards greater accuracy and reliability.

Mr. M. J. Tucker, (Member 1965) was appointed an Assistant Director with the Institute of Oceanographic Sciences in 1974 and is now in charge of the Institute's establishment in Taunton, Somerset. This deals with research into coastal sedimentation and with oceanography applied to engineering problems and he is also responsible for the Institute's Marine Scientific Equipment Service at the Research Vessel Base at Barry, which provides oceanographic equipment for universities and NERC bodies. He was formerly Head of the Applied Physics Group at the Wormley establishment of IOS, originally the National Institute of Oceanography, which he joined in 1950. Mr. Tucker has been a pioneer in the application of electronic and acoustic techniques to oceanographic instrumentation, having first entered this field during the War with the Oceanographic Group at the Admiralty Research Laboratory, and he has contributed several papers to the Institution's Journal. He has served on the organizing committees of two IERE conferences in this field.

An important trend has been towards the development of submersibles, both manned and unmanned (submersibles are distinguished from submarines by being small and not designed for warfare). This development has an interesting history. As part of the rather emotionally-based push towards underwater technology in the late 1950s and the 1960s, a large number of submersibles was built: Flemming⁴ lists 42 in existence by 1966. This flowering was not, however, based upon a proper assessment of their uses and this became obvious by the late 1960s when the effort effectively collapsed and a period of reappraisal set in. Only a small number of submersible types survived this period to take part in the resumed development from about 1970 onwards. This recent development has been based on much more realistic naval and civilian requirements and Vickers Oceanics, for example, now has a large fleet of submersibles being run as a flourishing commercial operation for both research and industrial applications.⁵

The developing use of submersibles and divers, and the increasing complexity of underwater operations has made it necessary to develop precise underwater positioning systems. For reasons described in the section on underwater acoustics these devices are all acoustic and they mostly work on pulse echo-time measurement. In most cases only relative position over a restricted area is required, and reproducibility of a fraction of a metre can be obtained. A typical system will have three acoustic transponders placed on the sea bed. The object whose position has to be fixed contains an interrogator which emits an acoustic pulse; when this is detected by the transponder it immediately sends out one of its own which is in turn received by the interrogator which measures the time delay. Three such time delays for three fixed transponders allows the position to be fixed. For more details of a typical system see Kelland.⁶

One trend there has *not* been is to oceanography from space. The only really important contribution of space technology to ocean technology has been the satellite navigation system. Combined with sophisticated dead-reckoning techniques and using elaborate computer programs, this enables a research ship to know where it is at any time and place in the world's oceans to within a few hundred metres at worst, and even more important, to calculate where it has been with an accuracy approaching 100 m.

All other satellite applications so far have been marginal. Probably the most positive has been the tracking of free-drifting buoys, some of which can telemeter a limited amount of environmental information. Each buoy is fitted with a drogue suspended at a selected depth so that it follows the path of a packet of water at that depth, and in this way some information can be obtained about drift currents. However, it is rather like tracking a balloon in the atmosphere: a single experiment tells you little about the typical patterns, and can only be properly interpreted if combined with other information such as long continuous measurements at fixed positions. Claims are made about measuring waves from space, but at present all that can be obtained is a rather ill-defined measure of

roughness: this can be useful qualitatively but for most purposes well-defined quantitative measurements are required.

One application which could turn out to be important in the future is tidal measurement over the open ocean. This depends on very precise measurement of the altitude of a satellite coupled with precise knowledge of its orbit. In principle this could allow measurement of the change in surface level of the sea due to tides on an ocean-wide basis, which can only be done at present by a slow and expensive process of installing self-recording tide-gauges for appropriate periods at selected positions on the ocean bed. Accuracies now being claimed are sufficiently close to being useful for tidal researchers to start taking the method seriously.

Data Buoys

A great deal of effort is at present being expended on the development of large data buoys⁷ (see Proc. European Symposium on Offshore Data Acquisition Systems 1974) and attempting a co-ordinated policy under the COST organization (Co-operation in Science and Technology), with the object of establishing a European network of perhaps 40 buoys. Individual countries, and above all the USA, have been spending large sums on the development of such buoys for years. The UK should have its first large buoy operational this year.

Briefly, the state of the art at present is this. The US has concentrated on large discus buoys 40 ft in diameter, though latterly some smaller ones have been built. They claim that the buoy, its moorings, power supplies and telemetering system can survive and remain operational for at least a year both in continental shelf and deep ocean waters. The basic meteorological sensors can survive, though doubts have been expressed as to whether they maintain their accuracy. However, apart from temperature, it seems that no-one has yet developed oceanographic sensors which can be relied upon after 2 or perhaps 3 months in the sea. European countries have concentrated more upon spar buoys, though the UK DB1 is a discus type. (See Fig. 1.)

Discus buoys are designed to be boarded for servicing equipment, but this is very difficult except in calm weather. Spar buoys are long vertically with most of the length submerged and are designed to be removed from the water completely for servicing. The other main operational difference is that directional wave spectra can be calculated from the pitch, roll and heave of the discus buoy since it follows the water surface, but no-one has yet developed a method for recording directional wave spectra from spar buoys. Spar buoys are cheaper than discus buoys because they can be smaller and simpler. The relative merits thus depend on compromises and opinion has not yet really settled down. Perhaps the most critical question is 'how important is it to measure directional wave spectra?'. Which leads us on to the question of the applications of these buoys. This should, of course, have come first, but historically it did not and early buoys tended to be solutions in search of problems (I was once at a meeting which the Chairman



Fig. 1. The prototype UK National Data Buoy under construction for the Department of Industry in the yard of R. H. Green and Silley Weir on the Thames. It is planned for the buoy to be on station near the Smith's Knoll lightvessel off East Anglia by late summer 1975.

opened by saying 'Gentlemen, we have spent £1.5M developing a buoy: if anyone can think of anything useful to do with it we will fund it'). It is only quite recently that careful thought has been given to this question. The answer is that the most important use world-wide seems to be to measure meteorological parameters. In the UK, for example, most of our weather comes from the Atlantic and the Meteorological Office could make good use of the information from a number of fixed stations to the west of the British Isles. This could become even more important if the Ocean Weather Ships are withdrawn at some future date. However, we have other important oceanographic uses in connection with forecasting storm surges, fisheries problems, gaining environmental data for offshore structures and research, and as truth points for real-time wave forecasting systems.

One of the difficult problems which will be of particular interest to IERE members is the radio telemetry system. Everyone starts by saying that the obvious answer is to telemeter via satellites. This is one of those cases where it always seems likely to be the answer in 5 years time, but never now. There is either no suitable satellite in orbit, or the complication and power consumption of the buoy-mounted station are too great, or the commercial charges are too high, or the sheer logistics of getting the data to the user in near real-time are formidable, etc. Thus, one has to fall back on

conventional methods, and here the h.f. band is the only real possibility. Fortunately, some far-sighted oceanographers (in particular Jim Snodgrass of the Scripps Institution of Oceanography of the University of California) foresaw the need many years ago and managed to obtain international agreement at the World Administrative Radio Conference in Geneva 1967 for the allocation of bands for this purpose. There are six oceanographic h.f. bands at approximately 4, 6, 8, 12, 16 and 22 MHz. Each band is 3 kHz wide divided into 10 channels each 300 Hz wide (including guard bands). However, transmission in these bands using normal methods is nowhere near reliable enough for the present purpose. IOS has spent a lot of time looking at this problem, and concluded that the best solution is a multiple-frequency-shift keying system (m.f.s.k.). Oddly, although this seems to be described in most of the textbooks, we know of only one practical realization of it. This is the Piccolo system developed by the Diplomatic Wireless Service in the UK⁸ and a measure of its performance is that it has been used to transmit daily newspapers to ships in the North Atlantic with fewer mistakes than in the paper as normally printed: it will do this even through other transmissions on the same band. However, we are having the greatest difficulty in getting this accepted internationally because it is unconventional and does not fit neatly into the more normal specifications.

The reasons why the m.f.s.k. system is so much better are briefly as follows. In the h.f. band, transmission is by both ground wave and a number of reflexions from layers in the upper atmosphere. The maximum time differences between these paths are of the order of 40 ms. In these circumstances the normal short-pulse system tends to get confused. In the m.f.s.k. system frequencies are specified at 10 Hz intervals in the channel, each frequency representing a symbol and only one frequency being transmitted at a time using 100 ms pulses. This gives a data rate not too much below that of the usual binary system, but since the pulses are much longer than the path differences, a properly designed receiving system does not get confused. A more subtle advantage concerns interference, the main effect being that short transient or impulsive interference produces peak power proportional to the square of the bandwidth, giving the narrow band a great advantage.

Underwater Acoustics

The range of propagation of electromagnetic waves in sea water is extremely limited, so that except for some short-range optical work, virtually all the work that is normally done in the atmosphere by radio, radar and optics has to be done in the sea using acoustics, in so far as it can be done at all. Fortunately acoustic waves propagate reasonably well (Fig. 2) and in fact signals can be propagated half-way round the world using very low frequencies in the SOFAR sound channel.⁹ However, the absorption of sound increases rapidly with frequency so that for ranges over about 10 km for example we are limited to frequencies below about 10 kHz. Since the wavelength at 10 kHz is approximately 15 cm, this limits the realizable resolution rather severely. Other

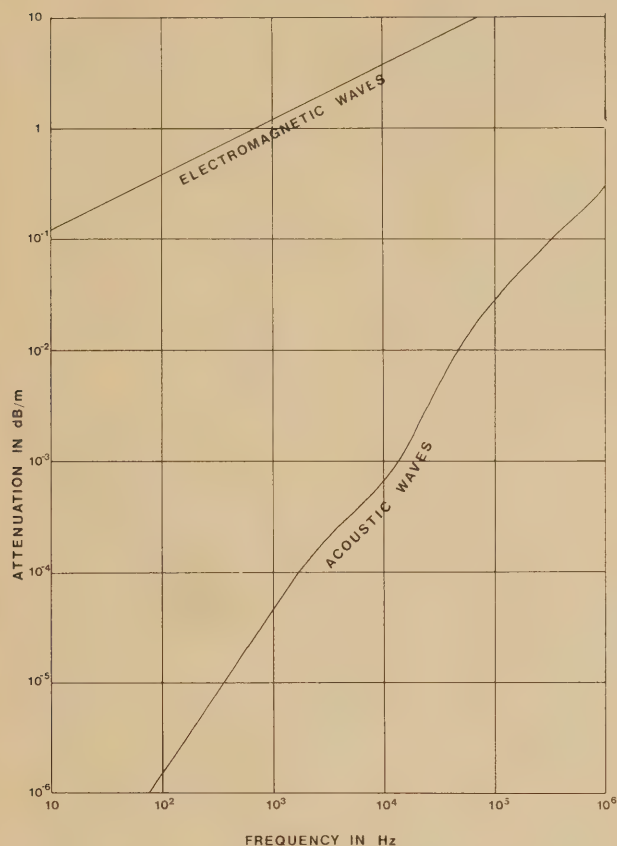


Fig. 2. The attenuation of sound and radio waves in the sea for typical temperature and salinity.

limitations are introduced by the comparatively slow velocity of propagation (approximately 1.5 km/s) which limits the data rate, and by refraction effects due to variations in temperature and salinity which can in extreme circumstances reduce effective ranges to a few hundred metres.

The greatest effort has gone into sub-bottom 'seismic' sounding because this is the primary tool for oil exploration at sea. The sea here acts as a very convenient 'slip-ring' for coupling sound pulses into the sea bed from and to sources and receivers towed from a continuously moving survey vessel. Great effort and sophistication have gone into computer methods for processing the signals, and several papers on this subject were presented at the Seventh Annual Offshore Technology Conference in 1975.¹⁰

The most exciting UK development in the past few years has been a long-range side-scan sonar code named GLORIA (Geological Long Range Inclined Asdic). (Sonar, which used to be called Asdic in the UK, is the underwater acoustic equivalent of radar.) This consists of a large towed body 10 m long and 1.5 m diameter containing a transducer array 5 m long and 1.2 m wide operating at 6.4 kHz. This can transmit pulses with an acoustic power of up to 50 kW and with a duration of up to 4 s. Stretched pulse and matched-filtering techniques are used which increase the effective pulse power by a further factor of at least 100 with an effective pulse

length of about 10 ms. In practice the range achievable is limited by propagation conditions. In the deep ocean ranges of up to 24 km can usually be obtained, and ranges of up to 13 km have been obtained over the continental shelf in favourable circumstances. Figure 3 shows an example of the acoustic pictures of the surface of the sea bed obtained with this equipment. (A general description and some early deep-sea sonographs are given by Rusby and Laughton^{11,12} and a good example of its capabilities in shallow water is given by Rusby *et al.*¹³)

Another interesting development has been the neutrally-buoyant acoustically-tracked floats. These depend on the fact that sea water is comparatively compressible, the increase in density due to pressure alone being 1% at a depth of about 2300 m for example. Thus, it is possible to make pressure cases of aluminium alloy which will withstand high pressures, have sufficient buoyancy to support acoustic equipment and power supplies, and which are less compressible than sea water. Suitably ballasted, these will sink to a predetermined level where their weight equals that of the water displaced, and then float around with the water at that level. They carry acoustic beacons which enable them to be tracked over considerable periods of time.

The most spectacular version of these floats has been developed by the Woods Hole Oceanographic Institution in the USA. The main pressure case consists of an aluminium alloy tube approximately 5.2 m long, 30 cm diameter, and 2.5 cm thick. The acoustic transducers are external tubular resonators driven by piezoelectric benders, and the whole weighs 430 kg. They transmit approximately 4 W of acoustic power at a frequency of 270 Hz in pulses 1.5 s long with a p.r.f. of 1 per minute (figures are approximate). They operate in the SOFAR layer, which is a layer of minimum acoustic velocity centred at a depth of approximately 1.3 km and which acts as a sound-trapping channel giving the floats an acoustic range of 1000 km. The pulses are received by hydrophones at Bermuda, Puerto Rico, the Bahamas and Florida. Thus, if operating in a suitable area between these stations they can be tracked for many months using the time of reception of the pulses. They are recoverable, and measure and record internally the pressure (giving the depth of the float), temperature and the vertical velocity of the water past them. No recent description of them has been published, but Rossby and Webb have described an early version¹⁴ and given some results using it.¹⁵

In the UK we have developed smaller floats with transponder beacons operating in the band 5 to 6.5 kHz which are tracked using an interrogator lowered from a ship: this sends out a pulse the receipt of which causes the float to emit another on a slightly different frequency which is received by the ship. These have acoustic ranges of up to 70 km or more (depending on conditions) and a field of up to 22 of them can be tracked at one time.³ They have a duration of up to approximately 30 days. A separate acoustic command system is used to cause them to jettison a ballast weight so that they rise to the surface for recovery.

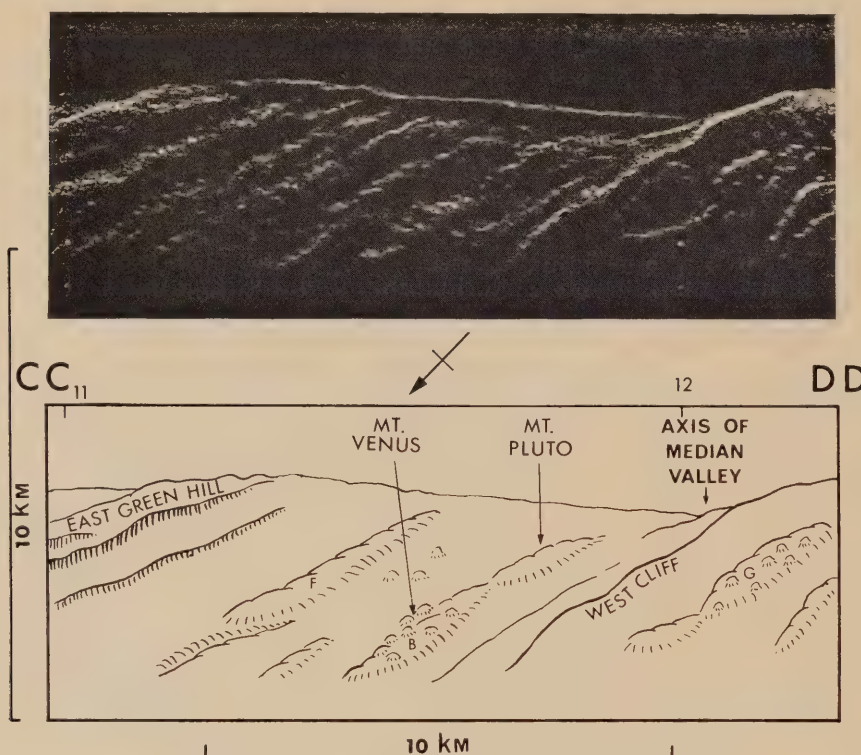


Fig. 3. Side-scan sonar traverse obliquely across the median valley of the Mid Atlantic Ridge using the GLORIA sonar. It shows the volcanic ridges, Mt. Venus and Mt. Pluto, where new ocean crust is being generated as the American and African plates separate. Note that some acoustic energy is transmitted vertically beneath the ship to give an unexaggerated profile of the valley, while at maximum range (6 km) the bottom is viewed at a low angle (for more details see Loughton and Rusby¹²).

It is not possible to cover all developments here, but one could not leave the subject without mentioning sector-scanning sonar. Early developments of sector-scanning sonars for naval use commenced soon after the end of the last war, and one of these developed at the Admiralty Research Laboratory was made available to the Fisheries Laboratory at Lowestoft for evaluation and use as a fisheries research tool. The Fisheries Laboratory has developed a modernized version of this for their own use, and the Department of Industry has funded the commercial production of a version designed primarily for hydrographic surveying. Considerable research into the design of sector-scanning sonars has also been carried out in the Department of Electrical and Electronic Engineering at the University of Birmingham. Sector-scanning sonar overcomes the data-rate problem by 'illuminating' a sector of the sea or sea floor with a pulse of sound, and then scanning a narrow receiving beam rapidly through this sector, each scan taking less time than a pulse-duration. The main sophistication, of course, lies in the electronic arrangements for producing the scanning from a fixed array of receiving sensors. The result is an almost television-like picture of what is going on in the sea or on the sea-bed, which can be extremely useful in a range of applications from research on the behaviour of fishing nets to hydrographic surveying. An example of a record is given in Fig. 4 but stills do not do justice to the quality of the moving display.¹⁶

Outstanding Problems in Oceanographic Instrumentation

Rather surprisingly, the most stubborn problem in oceanographic instrumentation remains the absolutely

fundamental one of the measurement of water currents. A great deal of effort is now being put into this, but the problem still has not been satisfactorily solved. The problems are of two types: operational problems of reliability, emplacement and recovery; and the fundamental ones connected with the design of the sensor. There is room for improvement in the first type of problem, but a data recovery rate of typically 70% is being obtained, which makes the operation worthwhile. The sensor problem has still not been solved.

As mentioned in the introduction, the time scale of processes in the sea is such that, except for special cases, measurements of current lasting less than a few weeks have little meaning and usually we would like continuous measurements for a year or more. Self-contained recording current meters are therefore essential. The usual specification requires the mean current over a period of typically 10 min to be measured and recorded. The current meters developed 10 years' ago, which are still in common use, consist of a rotor working on the principle of the cup anemometer but of different design, whose revolutions are counted and recorded at the appropriate intervals. At the moment of recording, the direction of the current is measured and recorded using a vane and magnetic compass. The main problem with this system is that the rotor measures the speed of the current independent of its direction, so that errors are introduced in a turbulent current or one disturbed by wave motion. The situation is not too bad if the current meter is on a steady platform in a fairly steady current with only normal turbulence present: errors in mean speed are probably less than 10% and significant noise is introduced only at high frequencies which are often



Fig. 4. An acoustic picture of a wreck lying on the sea-bed taken with the sector-scanning sonar. The hatch covers can be clearly seen and a rough profile of the superstructure is given by the outline of the shadow behind. Range to centre of ship approximately 80 m: range markers on ordinate at 20 m intervals: abscissa is bearing with 30° across the record. (Photograph by courtesy of the Fisheries Laboratory, Lowestoft.)

not important. However, where one is measuring at depths to which wave motion can reach, or if the meter is suspended below a buoy moving about with the waves, then large errors can be introduced. Various attempts have been made to overcome this problem. The availability of c.o.s.m.o.s. logic circuitry made it feasible to make frequent rapid measurements of current speed and direction, compute the N-S and E-W vector components, and accumulate and average these for several minutes following which these vector averages are recorded. Such a meter (termed the vector averaging current meter) was developed at the Woods Hole Oceanographic Institution and some batches have been manufactured and extensively tested. Although better than previous meters, they still give large errors which have been traced to the non-linear properties of the rotor sensor used. This has considerable inertia due to the trapped water and so does not follow rapid fluctuations in current speed. The torque is roughly proportional to the square of the water velocity and so it speeds up

faster than it slows down, producing a rectifying action. Impellers (that is, rotors in the shape of propellers) have much better properties in this respect but are not so easy to use.

Hope then concentrated on electromagnetic current meters. These operate on the principle of the dynamo: a coil generates an alternating magnetic field and the conducting water passing through this generates an e.m.f. which is detected by electrodes acting as slip-rings. By using two pairs of electrodes, the two components of the velocity perpendicular to the magnetic field can be measured. Such meters have been used in cable-connected form and as ships' logs for some decades,¹⁷ but the availability of compact low-power semiconductors has recently made it feasible to think in terms of self-contained meters. Several have been developed in the USA but none has yet been passed as satisfactory by oceanographers. The problems again lies with the sensor. The first dilemma is this: if a streamlined ellipsoid containing a flat coil is used, it 'stalls' if tilted at too great an angle to the current (that is, the flow becomes turbulent) and the calibration changes abruptly. This is a snag in waves for example. If to avoid this a circular spar containing a long coil is used, this always results in turbulent flow giving high noise levels and a slightly non-linear calibration. The second difficulty is that no way has been found of mounting them which does not involve some sort of cage round the sensor. It turns out that the volume in which the flow is sensed is rather a small one close to the electrodes, so that when these are in the wake of one of the cage members a kink in the directional response results.

A further major problem with these more sophisticated meters is cost. Because of the hazards of working at sea (in shallow water, mainly being interfered with by trawlers, and in the deep sea, mainly technical problems) about 25% of current meters are lost on average at each deployment. Since a typical installation carries three or four meters, it becomes expensive if the current meters cost, say, £4,000 each.

Oceanographic instrument engineers are now looking at acoustic current-meters for this application since they offer solutions to at least some of the problems, but no self-contained current meter of this type has yet been fully evaluated. Thus, the problem of current measurement in the ocean still awaits a satisfactory solution. (A fuller discussion is given by McCullough.¹⁸)

To finish both this section and the essay, I would like to mention the problems of instrumentation in the field of research into sediment movement in the sea, with which I have become involved in the last two years. Coming from comparatively well-served branches of oceanography the inadequacy of techniques in this field was striking. It is hardly an exaggeration to say that were it not for the availability of the cable-connected version of the electromagnetic current meter it would be almost impossible to do meaningful research into the basic dynamics of non-cohesive sediments, and the same is almost as true of the radioactive density gauge and research into cohesive sediments (that is, 'mud'). For the non-cohesive sediments (mainly sand) we require,

above all, instruments to measure rates of transport: we are trying impact-measuring devices for suspended sediment, and hope to look at acoustic Doppler techniques for bed-load transport. For cohesive sediments the requirements are not yet so clear, but certainly include devices to measure the rheological (flow) properties.

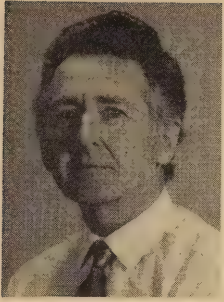
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Medical Electronics

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The application of electronics to medicine did not follow an expected course of being delayed somewhat upon original technological developments. Instead, apart from specific applications, the subject found no general application until the value of electronics in radar and communications had been clearly demonstrated. Thus the main impetus came with a delay approaching fifty years so that the medical applications have occurred mainly in the past twenty-five years.

Introduction

The therapeutic effects of electricity were appreciated some 2000 years ago by the philosophers of the time who referred to the effects of the torpedo fish.¹ This is now known to be caused by a 50 V pulse from a source impedance of 10 Ω . However, it was not until the 18th century, with the increasing awareness of electrical phenomena, that its possible value for medical treatment began to be explored. Looking back at the often bizarre applications (Fig. 1) it is now clear that the application of engineering technology in medicine demands an understanding of both technology and its medical effects.

The very beginning of the 20th century saw the birth of electronics but this time there was no eagerness on the part of the medical profession to see what happened when thermionic devices were applied to the patient. A notable exception was the use of X-rays, for their property of penetrating substances opaque to light opened the way for photographing internal structures of the body.² This technology has since proved of inestimable value, initially for diagnosis, then the realization that larger doses caused skin reactions led to therapeutic developments for selective destruction of tissue at specific sites. In 1890, D'Arsonval used high-frequency Hertzian waves to stimulate skeletal muscle and found that at 10 kHz the muscle response was insignificant and that above 100 kHz heat was produced through ohmic dissipation in the tissue. Early high-frequency diathermy used a spark gap and induction coil and it was thus a natural development to replace this with a thermionic valve when this had established its value in radio communication. Other developments utilizing electronics were mainly confined to research departments. Physiologists since Galvani have been interested in the electrical activity of muscle and nerve so that workers, such as

A. V. Hill at University College London, who used sensitive galvanometers for their measurements were eager to obtain greater sensitivity by the introduction of thermionic amplifiers.

The real impact of electronics in medicine had to await the post-war period, when the experience gained in military development was able to be applied in other fields. By then the two professions of medicine and engineering had become too diverse for one person to be expert in both, and the subject of Medical Electronics developed in an *ad hoc* manner throughout the world. In 1958 Dr. Vladimir Zworykin, who through this work on electron microscopy and his own personal interests had become aware of the potential of electronics in medicine, called a meeting in Paris of some eighty persons who had become known internationally for their work in this new field. The author attended this meeting and represented the Institution which in the following year established its own Medical and Biological Group with an inaugural lecture by Prof. A. V. Hill.³ The Paris meeting led to the formation of an International Federation of Medical Electronics (later to become Medical and Biological Engineering) in 1959, whilst in the UK the Biological Engineering Society was formed in 1960.

The impact of engineering in medicine throughout the world has been impressive and electronics has first improved measurement procedures and then provided new techniques for treatment and surgery, in addition to more sophisticated procedures for processing, analysis and control.⁴ The whole area of Medical Electronics is too wide for an adequate description here, but Table 1 gives some idea of the respective areas in which electronics has been applied to medicine. Some of these applications that have made a new contribution to medicine, as distinct from improving existing methods, will be discussed. A more comprehensive description of the subject is available in 'Medical Engineering',⁵ whilst current advances are described in the *Annual Reviews of Biophysics and Bioengineering*.⁶

Radiology

The value of X-rays is now well established and the major problem has been to reduce the dosage for diagnostic use and to localize the beam, and to avoid scatter during therapy. The image intensifier has helped considerably in reducing dosage and can be combined with video recording to provide a continuous display for pulsed X-rays and so further reduce dosage for viewing the dynamic operation of organs. A recent develop-

Mr. Jack Perkins (Fellow 1957, Member 1951) has been concerned with the applications of electronics to medicine and biology for nearly thirty years—he has been with the National Institute for Medical Research since his demobilization from the RAF in 1946. He was initially in charge of the Electronics Laboratory and with the growing importance of computer methods in medicine he formed the Computer Science Laboratory in 1970. Mr Perkins was the first chairman of the Institution's Medical and Biological Electronics Group Committee, set up in 1959, and he helped to found the Biological Engineering Society in 1960, later becoming the Secretary and then President. He was also the President of the International Federation for Medical and Biological Engineering from 1963 to 1965.

Table 1

CARDIOLOGY		PATIENT MONITORING	
Electro-cardiography (e.c.g.)	Electrical potentials at electrodes on the surface of the body due to heart muscle movement.	Coronary care	Continuous measurement and recording of patient data in these Units, sometimes with alarms at predetermined levels.
Vector-cardiography (v.c.g.)	Vector representation of heart potentials from pairs of electrodes to indicate the direction and repolarization of heart muscles.	Intensive care	
Phono-cardiograph (p.c.g.)	Heart sounds picked up by microphone and analysed for specific defects in cardiac blood flow pattern.	Isolation unit	
Cardiac output	Determination of blood volume passed through the heart as an indication of its efficiency.	Operating room	
Cardiac catheterization	Tubes passed through arteries and sometimes veins to specific sites in the heart for measurement of cardiac parameters.	THERAPEUTIC TECHNIQUES	
Defibrillators	Provide electrical potentials to depolarize uncoordinated activity of muscle cells of the heart (fibrillation).	Diathermy	Warming of internal tissues by Hertzian waves above 10 kHz.
CIRCULATORY SYSTEM		Ultrasonics	Treatment of the ear, destruction of stones in bladder.
Blood pressure	Records the pulsating pressure of the blood from a maximum (systolic) when the arterial valves are open, to a minimum (diastolic) when the arterial valves are closed.	X-rays	Destruction of tumours and skin cancers.
Blood flow	Measures the rate of flow of blood at a given site.	Particle accelerators	High energy electrons for localized direct beam or the production of X-rays by collision.
Blood gas analysis	Determines quantities of respiratory gases (O ₂ and CO ₂) in the blood at a given site.	DIAGNOSTIC TECHNIQUES	
Blood chemistry	Chemical analysis of blood to determine proportions of constituents.	X-rays	Imaging of bone structures for examination of fractures, location of foreign bodies and tumours.
Properties of blood	Measurement of physical properties, such as viscosity.	Ultrasonics	Examination of soft tissues, detection of tumours, blood flow.
RESPIRATORY FUNCTION		Nuclear medicine	Labelling of organ or site selective substances for studying their take up of blood or drugs. Also for determination of shape.
Spirometers	For measurement of air flow.	Thermography	Temperature profile of the body surface for determination of abnormalities in the underlying vessels.
Gas analysis	Analysis of respiratory and anaesthetic gases.	SURGICAL TECHNIQUES	
Gas exchange	Assessment of effectiveness of lungs in transfer of O ₂ and CO ₂ across membranes between air sacs and blood stream.	Diathermy	For coagulation of vessels as they are cut. Destruction of diseased tissue.
Respiratory mechanics	Determination of lung capacity in terms of maximum and minimum volumes, also compliance (dv/dp).	Lasers	For more precise coagulation of tissue as in the brain.
NERVOUS AND MUSCULAR SYSTEM		FUNCTION REPLACEMENT	
Electro-encephalography (e.e.g.)	Recording of neural potentials from electrodes on the scalp.	Heart-lung	To take over the action of this system for long-term heart operations.
Frequency analysers	Determination of levels of different rhythms in the e.e.g. waveform.	Artificial hearts	To assist failing hearts.
Stimulators	Pulse generators to provide precise electrical stimuli to the muscular or nervous system.	Renal dialysis	To take over the function of the kidneys in removing waste products from the blood.
Electro-myography (e.m.g.)	Recording of potentials due to muscular activity.	Cardiac pacemakers	To stimulate the ventricles of the heart directly when these are not stimulated from the physiological signals at the atrium.
MISCELLANEOUS		Bladder stimulation	For control of urinary incontinence when normal muscular control is lost.
Ophthalmology	Eye movement, laser probes.	Speech	To replace the sound source when the larynx has been removed but control through the mouth is still available.
Obstetrics and gynaecology	Pressure in the uterus, heart rate, foetal e.c.g. and e.e.g. Ultrasonic display of foetus.	TECHNOLOGY	
Digestive system	Pressure in the stomach and digestive tract.	Telemetry	Transmission of biological signals such as e.c.g., pressure, etc., from a person to a central unit.
		Television	For medical education. Displays of patient data. Video recording of X-rays.
		Computers	Processing and analysis of biomedical signals. Processing and analysis of radiological images. On-line monitoring of patient data. Simulation of biological systems. Decision making in diagnosis.



Fig. 1. Early attempt to cure deafness by the application of an electrostatic discharge.

ment that is proving of great interest is the EMI Scanner (Fig. 2), which incorporates a computer for the purpose of building up a series of absorption values as an X-ray source and scintillation counters are scanned linearly, then rotationally about the head.⁷ The use of scintillation counters and a computer to produce the display allows a much greater resolution to be obtained than with X-ray film without increasing the radiation dosage. For the brain scanner a matrix display of the X-ray absorption of the brain tissue in a given region is obtained which can indicate the presence of lesions. A further development is now available that can be used for scanning all parts of the body. High-energy electron therapy for the selective destruction of tissue can be obtained from particle accelerators by taking electrons through a thin metal window for the direct radiation or to supplement high energy X-rays when the high-speed electrons collide with a heavy metal target.

Ultrasonics may also be used both diagnostically and therapeutically as complementary to X-rays in that they are better suited to the examination of soft tissues and

less for bone.⁸ In the conventional A scan technique, the transducer is fixed with respect to the object and the reflected response is displayed on a cathode-ray tube screen as a function of time from the transmission of the pulse. The B-scan technique is used for building up pictures of organs by moving the transducer over a given area and using the reflected beam to modulate the brightness of the cathode-ray beam. Being less hazardous to the patient than X-rays, ultrasonic waves are of particular value for the examination of a foetus.

In nuclear medicine, the isotope uptake in a given region can be determined by scanning the area with a single scintillation counter and plotting the activity for each finite position.⁹ The necessary low level of radioactivity used in order to minimize the dosage requires a long counting period to discriminate effectively against random background noise and so for reasonable accuracy the scinti-scan method can be rather slow. Alternatively, a plot of activity can be obtained using a gamma camera in which a series of counters are arranged in a matrix over the area to be measured.

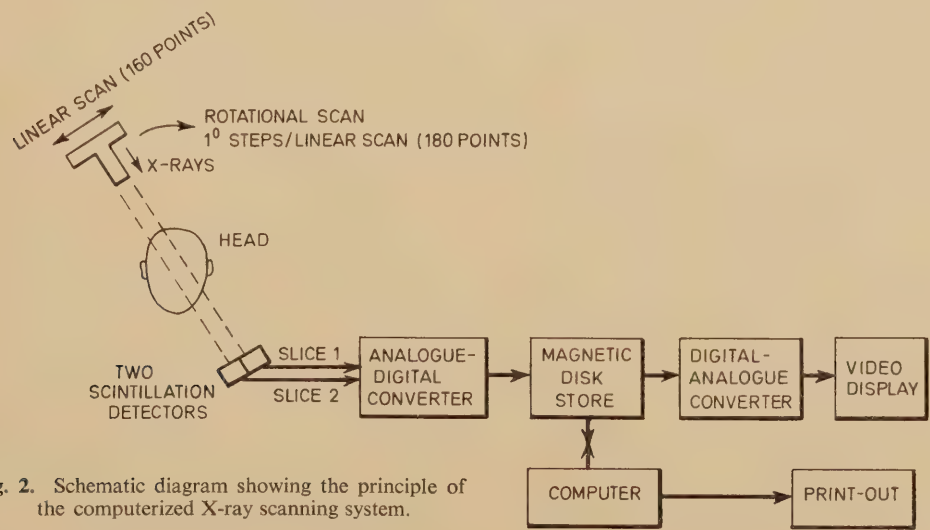


Fig. 2. Schematic diagram showing the principle of the computerized X-ray scanning system.

Cardio-vascular System

Disease of the heart and its associated circulatory system is a major contributor to ill health and represents an area for increased medical interest and in which technology has played a major part. Initially advances were due to more sensitive measurements of cardiac and respiratory function. Improvements in recording the electro-cardiogram (e.c.g.) have led to more detailed analysis of the waveforms as they can be indicative of cardiac defects (Fig. 3) in that the waveform of electrical activity is related to the muscular movements of the heart. Figure 4 shows the various chambers of the heart. Physiological signals at the sino-atrial node determine the heart rate as these pulses are transmitted through the muscle bundle of His to contract the ventricles. This forces oxygenated blood from the left ventricle through into the vascular system and the impure blood from the right ventricle into the lungs where it is reoxygenated and cleansed of carbon dioxide then returned to the heart through the left atrium. Thus different sections of the waveform relate to periods during each cycle of contraction and relaxation of the heart muscles. Initial contraction of the atrium (P wave) is followed by the main contraction of the ventricles (QRS) then recovery (T wave). The electrical signals on the body surface are of the order of 1 mV for a normal R wave.

Once a relationship between the waveform and a particular disease can be recognized and defined by an expert, the possibility arises for technology to provide a more general application. Thus the waveform is digitized and fed into a computer which recognizes established features and relates them to the appropriate cardiac defect.¹⁰ The conventional connexions for e.c.g. recording are, right arm, left arm, left leg, but for a more detailed analysis, more electrodes are used in specified positions, a common grouping being either 7 or 12 leads.¹¹ These may be analysed individually or weighted to produce the equivalent of three orthogonal planes, any two vectors of which can be combined to produce a Lissajous figure for that plane. Using a computer, this three-dimensional shape can be displayed in depth and also rotated to show changes.¹² Most cardiac defects may be detected from the e.c.g. but some may be more readily observed from the vectorcardiogram.

Considering therapeutic developments, defibrillators undoubtedly save many lives daily whilst cardiac pacemakers have enabled persons with major cardiac defects to lead sensibly normal lives. Electronically, both are simple devices, the defibrillator producing voltage pulses to paralyse a heart in which uncoordinated activity of the muscle cells of the ventricle occurs (fibrillation).¹³ The pacemaker is also a stimulator that is implanted, with electrodes connected so as to stimulate the left ventricle directly when natural physiological stimulation has failed to operate through some cardiac defect.¹⁴ Should the normal sinus rhythm appear in conjunction with the pacemaker rhythm there is a danger of fibrillation occurring. To avoid this, demand pacemakers have been developed which are inhibited by any sinus pulses, also synchronous pacemakers where the stimulator is triggered from the low level signal at the atrium. The

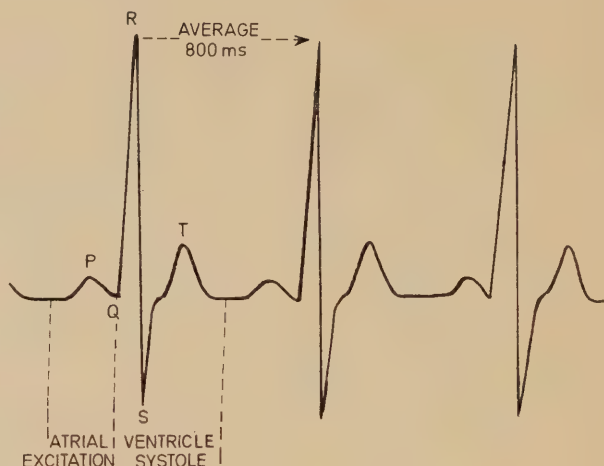


Fig. 3. Typical electrocardiogram (e.c.g.) showing identifiable peaks PQRST.

provision of energy sources and its conservation are the main problems at present although more sophisticated control from physiological parameters affecting the heart rate could enable younger persons with similar defects to lead more active lives.

A major advance following the introduction of semiconductor devices has been the use of catheter probes where transducers are placed at the tip of catheters which may be introduced into specific sites, such as cardiac cavities, through arteries. These are used to measure temperature, blood pressure and flow, oxygen content and cardiac output. Both electromagnetic¹⁵ and ultrasonic Doppler techniques¹⁶ are used for the measurement of blood flow during surgery (Fig. 5), and Doppler methods are also being used for non-invasive measurement of blood flow near the surface.¹⁷

The assessment of respiratory function requires a number of tests for determining breathing rate and volume, lung capacity and compliance, and the airways resistance.¹⁸ General machines combining these tests are now becoming available. A basic measurement is the air flow rate which is obtained using a spirometer, through which air is breathed and the difference in pressure across a restriction is detected by a transducer and fed to a differential amplifier. This pressure difference is proportional to the air flow over a wide range and can be recorded. By inserting one-way valves in the mouthpiece the expired air flow is obtained and integration of this waveform can provide the air volume over a given period. Gas chromatography is suitable for analysing anaesthetic mixtures and mass spectrometry is used for respiratory gases, continuous analysis being achieved by scanning the accelerating voltage. Apart from oxygen and nitrogen, all other relevant gases have absorption bands in the infra-red so this technique is also used. The determination of oxygen in the blood is necessary for an assessment of gas exchange, for which para-magnetic, polarographic or optical absorption techniques may be used.¹⁹

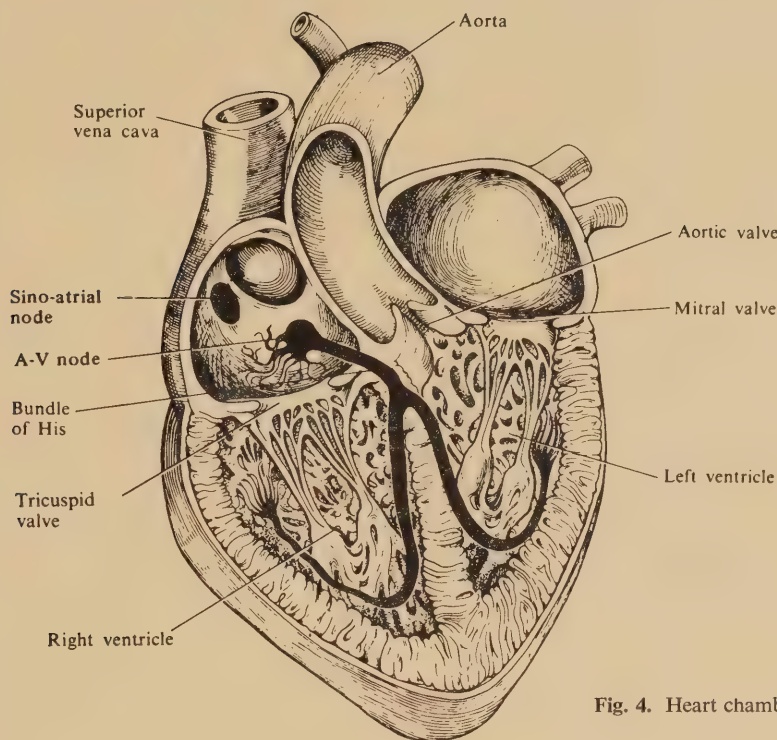


Fig. 4. Heart chambers and main vessels.

Neurology

Electrical activity of the order of a few microvolts may be picked up by surface electrodes on the scalp and amplified.²⁰ Numerous electrodes are required to adequately locate areas in the brain but this naturally leads to a large quantity of data which can complicate the analysis. The usual compromise in clinical practice is to use 16 electrodes. Recordings from these electrodes show characteristic rhythms within a range 2–75 Hz and any deviation in these rhythms may indicate some abnormality. Early problems of separating these ultra low frequencies into finite bands have largely been overcome, either by using active filter networks or by direct processing in a computer. The electro-encephalogram responds to various forms of stimuli, such as aural, visual, mechanical or electrical, and recording of the evoked response is therefore widely used in the study of animal behaviour. Similarly it has application for the newborn in the early detection of defects.

Technology

X-rays and ultrasonics are examples of a general technology finding a specific application in medicine. The use of infra-red sensors for displaying temperature profiles of body surfaces enables warm spots to be detected and these may be caused by disturbance of the blood flow in these regions due to underlying tumours.²¹ Being non-hazardous, this technique of thermography is of particular value in the pre-screening stage and has been applied to the early detection of breast cancers.

Communication techniques have found application in telemetry for behavioural studies on animals and this may be extended to environmental and industrial studies on humans.²² In the hospital situation, patient moni-

toring is usually confined to immobile patients in the coronary or intensive care units, where connecting wires are not a major problem, but telemetry of clinical data may be of value in the isolation units. The ability to transmit biological waveforms, such as the e.c.g. or e.e.g., to any part of the world does open up the possibility of providing expert diagnosis for areas with limited medical facilities.

Computers are a major technological development that have made an impact in almost every discipline. They have found ready application in the processing and

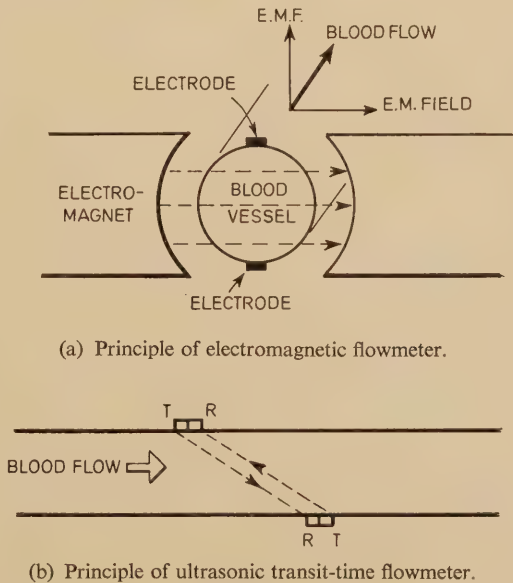


Fig. 5.

analysis of biomedical data and are now being used at the level of decision making. Of specific interest in medicine is the possibility of detecting trends in the processed biological data that could not be observed or even deduced from examination of the basic data.²³ Although everyone is aware that the human body is a complex control system there is still little effort in studying its behaviour as such. It is in this type of approach that, in addition to engineering techniques, an engineering attitude is also required.

Television quickly found application for education and the display of radiographs from video recordings but as yet it has had no major impact in medicine. More precision has been added to the determination of the left ventricular volume, as an indication of cardiac efficiency, by scanning a radiograph of the ventricle with a raster to find the area and with the depth indicated by density.²⁴ The propagation and absorption of Hertzian waves has resulted in the establishment of h.f. diathermy as a general instrument for the warming of internal tissues. The later use of microwaves provided a more localized heating and lasers allow a very precise localized heat that can be used to coagulate or destroy specific tissues.

Assessment of the Contribution of Electronics

Looking back at the advances in medicine that have been made possible by engineering technology, there can be no question of its value. The treatment of major cardiac defects could not proceed without the numerous cardiological measurements that are now employed in conjunction with the temporary life support system available for heart-lung by-pass. The impact of electronics has been to provide a general improvement in the precision of clinical measurements and, through miniaturization, to allow of measurements inside the body. The replacement of lost function by implanted devices is possible but major developments in this area await the development of a compact long-life energy source or a system for energizing externally.

What may be questioned is whether electronics could have played a more effective part in advancing medical knowledge and health care or if the incorporation of technological developments into medicine could have been effected with less delay. It is surely clear that engineers can help to advance medicine but at present there are too few employed in a clinical environment and this is essential if a close liaison is to be established between the two professions. Professional institutions have a responsibility to see that their subject is effectively applied and normally this has been achieved by ensuring that those who practise engineering are professionally competent to do so. However, in applying engineering to medicine, some knowledge of both subjects is required, so this approach needed to be modified. The situation might have been improved in the early days of biomedical engineering if a closer liaison had existed between the professional engineering institutions and the medical profession for jointly assessing the possible role of technology and working together to ensure that engineering would be effectively applied in medicine.

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Electronics in Space

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Past, present and future uses of artificial satellites for relaying microwave communications are discussed and consideration given to direct broadcasting. In the not too distant future establishing communication with extra-terrestrial intelligence may well be a challenge for the engineer.

Long years ago, before even this Institution was founded, the Royal Society informed a certain Mr. G. Marconi that since radio waves travel in straight lines, and we live on a spherical Earth, transatlantic radio was not possible. If the Royal Society had added the words 'high fidelity radio communication' they would have been correct. Indeed, the proper use of microwave line-of-sight radio for transatlantic work had to await the development of the communications satellite some 60 years later.

Interest in space travel began between the wars, and the British Interplanetary Society was founded only eight years after the Institution. However, early interest in space was concentrated upon the propulsion aspect, and the forthcoming marriage of space and electronics had to await the publication of A. C. Clarke's paper on communications satellites in 1945.¹ The use of a satellite S above the radio horizons of both A and B permitted microwave transmission from A to S, and from S to B, thus bridging the oceans by microwave link. Clarke's paper further pointed out that at an orbital altitude intermediate between a 90-minute *Sputnik* and the 28-day orbit of the Moon there was an orbit taking one day, so that an easterly-launched satellite above the Equator would give the radio engineer an imaginary mast 22 300 miles high on which to place his aerials. This is called the geostationary orbit, as it appears to hover over one place on the Equator, although fuel has to be burnt from time to time to compensate for drift due to perturbations arising from the Earth not being a perfect sphere, and also for attitude control, to permit the use of directional aerials. Indeed, it might be said that A. C. Clarke

described all the new ideas in a modern Comsat, except for the transistor and the solar cell.

There the matter lay for at least 10 years, even though space experts (or space cranks as we were then called) were beginning to think of payloads as well as propulsion. In America Dr. J. R. Pierce of Bell Telephone Labs began to take the Comsat idea seriously, also R. P. Havilland of G. E. Philadelphia. In 1959 I formed the first full-time British commercial space team at Hawker Siddeley. We started by listing some hundred or so missions Britain might do in space. Most of these were crossed off again as not wanted, leaving the Comsat as a commercial space application and the spy satellite for military use. The third main sector, space science, was already in the capable hands of Sir Harrie Massey and the Royal Society.

As US law then forbade the use of their launch rockets for foreign commercial or military payloads, we were limited to *Blue Streak* and the payload which it would carry. Using *Blue Streak*, Arthur Clarke's stationary orbit looked a long way up, making payloads vanishingly small. Anyway, the 22 300 miles altitude is not really necessary for communications reasons. A decrease to one Earth radius (4000 miles) is sufficient to link places 120° apart, while the stationary altitude only increases the coverage to 170°. *Blue Streak* could launch a useful payload to these lower altitudes. We were thus forced to cut our coat according to our cloth, and examined lower orbits with interest.

Now, the initial launch of a satellite must take it to a speed of at least 18 000 miles/h if it is not to fall back to Earth. To reach communications altitudes, a somewhat higher speed is needed, up to the limit of 25 000 miles/h, which is the speed to escape from the Earth's gravity altogether. Between these two limiting speeds, the satellite will climb to an apogee, then fall back to perigee at the original speed. If the orbit is to be circularized, further fuel must be carried out to apogee, and fired there to develop the circling speed appropriate to that altitude. An optimization study showed us that the weight or mass of an attitude-controlled satellite had a flat optimum of about $\frac{1}{4}$ ton, so that *Blue Streak* with paraffin-liquid oxygen fuel would give us 4-hour orbits, or perhaps as much as 8 hours. Such orbits give useful service to a variety of places at a variety of times.

This led to a survey of telephone customers' requirements, namely, desirable routes, busiest time of use (few people like to be rung up at 3 a.m.), need for communi-

Dr. W. F. Hilton (Fellow 1968) graduated at Imperial College in aeronautics and from 1935 to 1946 worked on high-speed wind tunnels at the National Physical Laboratory and he subsequently held appointments at Johns Hopkins University, at the Royal Aircraft Establishment and with Armstrong Whitworth Aircraft. His involvement in space electronics dates from 1959 when he joined Hawker Siddeley Space Group as head of their communications satellite project. When this was concluded he was for a year Secretary of the International Astronautical Federation in Paris and from 1966 to his retirement in 1973 he was with the British Aircraft Corporation's Guided Weapons Division as Assistant to the Director of Engineering. During this period he was concerned, among other things, with the design of communication satellites. Dr. Hilton has published extensively on aerodynamics and space technology and is the author of several books and numerous papers including one presented at the Institution's Conference on Radio Techniques and Space Research in 1961.

cation (business and social), and need to talk the same language. Clearly the Commonwealth expected the UK to provide such a service as and when it became technically possible, and I still feel this was Britain's true role in space. America, on the other hand, did not have the same world-wide interests and outlets at that time, and was more inclined to concentrate on television relay satellites, which are somewhat different from telephone relay satellites. Finally, Russia and its political associates comprise a compact area, ideal for microwave links on the ground, with the possible exception of the Cuba link. The Post Office told us what they knew of demand by time and place, confirming our belief that the Northern temperate zone in daylight is indeed the plum for inter-continental telephone traffic. When we were carrying out this market survey the Post Office and Cable & Wireless somewhat smugly assured us that they had quite a stranglehold on the World's communications—indeed, a cablegram from one side of South America to the other had to come via London in 1959! Unfortunately, our failure to launch our own communications satellites has resulted in our having a much reduced stature in modern global communication.

Making a virtue of necessity, we then devised and publicized both Sun-seeking and Northern Hemisphere seeking orbits. Indeed, the 12-hour ellipse inclined at 63.4° to the equatorial plane which Dauncey and I suggested² was in fact adopted by the Russians for their *Molniya* Comsat, just as Arthur Clarke's stationary orbit was used by the Americans. Unfortunately for the sterling balance of payments, neither orbit could be patented, and so no dues were payable.

What is meant by a Sun-seeking orbit? Consider satellites in an elliptical orbit reaching out towards the Sun. During Atlantic daylight (11.00 to 18.00 G.M.T.) service will be given across the Atlantic. As the Earth rotates inside the orbit, darkness will descend upon the Atlantic, and the Pacific will in turn come into the sunlight and receive service, say from 20.00 to 06.00 G.M.T., and later the Indian Ocean will be served by the 06.00 to 11.00 period. Thus communications are taken away during darkness when not in use, and used elsewhere, and brought back ready for tomorrow. Of course, this orbit has to be turned 360° in space once per annum, to compensate for the Earth's annual journey round the Sun, but by a suitable choice of orbital parameters, this can be done free of charge. One likely candidate orbit of this type has apogee at 10 570 miles, and three equatorial satellites will give continuous world-wide coverage during daylight hours. Undoubtedly interest in these orbits will return as the stationary orbit fills up. Satellite transmitters working on the same frequency must be at least $2\frac{1}{2}^\circ$ apart to give discrimination between main beam signal, and undesired cross-talk side lobes. Hence we are limited to 144, and more probably to 80 active stationary satellites, and these will continue to provide the night time background service during the coming century, augmented by up to 400 'rush hour' satellites in lower orbits, filling the visible sky.

Since most telephones and television sets are located in the Northern temperate zone, we note that if the

orbital plane is inclined 63.4° to the equatorial plane, the $(5 \cos^2 63.4^\circ - 1)$ factor in the equation for the variation in latitude of apogee becomes zero. If therefore a satellite is launched with this 63.4° orbital inclination, and with apogee over say 40°N , the satellite will continue to have apogee over 40°N , and thus give preferential coverage to the Northern hemisphere, including even the North polar regions, which are omitted by all equatorial satellites. It does this at the expense of the time spent over the Southern hemisphere, by virtue of Kepler's law (the radius vector traces out equal areas in equal time), so that satellites linger at apogee, and rush past at perigee. Indeed, elliptical orbits in the 8 to 12 hour range of period might be called the poor man's stationary orbit, as the satellites spend at least two-thirds of their time almost hovering, and not necessarily over the Equator, but over any preferred latitude. It can be seen why the Russians may have chosen the *Molniya* orbit, for its polar coverage, and its payload economy. Incidentally, four *Molniya* satellites give continuous service with any one 'out', while it takes no less than six to do this for the stationary orbit. Indeed, there are three spare *Intelsat IV* satellites in orbit at the moment, ready to take over at a moment's notice.

Turning now to actual achievements, as distinct from theory, we may mention in passing *Courier*, which relayed a prerecorded tape; *Echo I* (100 ft dia.) and *Echo II* (130 ft dia.), orbiting balloons which passively reflected one speech channel by microwave across the Atlantic. Pride of place goes to *Telstar* which was placed in elliptical orbit, and although neither Sun-synchronous, nor Northern Hemisphere seeking, it gave excellent transatlantic television and telephone.

By 1961 the Hawker Siddeley Group realized that the GPO did not wish to launch their own Comsats, and my space team was dissolved. Many of the team went to RCA in New Jersey, who hoped to catch up with Bell Telephone Labs. The British choice was submarine cables with repeaters.

In 1963 the COMSAT Corporation went public, but the US Government retained the majority shareholding, and the UK had to be content with a mere 7%, mainly because it did not have its own orbiting hardware as a basis for negotiation. It now seems unlikely that the British will ever regain the position they once held in the World's communications. A series of satellites were now commissioned, starting with *Early Bird*, later called *Intelsat I*, launched in 1965. This satellite was spin stabilized, with axis N-S, with a squinted antenna which beamed a disk of r.f. power equally in all circumferential directions, but limited to the North Atlantic in latitude; satellite weight was 85 lb. Hughes Aircraft had penalty clauses if the lifetime was less than 18 months, but in the event made a good profit, as it worked for more than $3\frac{1}{2}$ years. This unexpected reliability of spacecraft electronics is one of the more surprising spin-offs. Perhaps preventive maintenance does more harm than good! Later marks of *Intelsats* were similar in design, weighing 190 lb (*II*), 334 lb (*III*), with mechanically despun antenna; 1610 lb (*IV*), with steerable spot antenna and 12 transponders, and 1760 lb (*IVA*) now

on the stocks. All have an external drum covered in solar cells to provide up to half a kilowatt of d.c. energy from the Sun, the energy conversion ratio being better than 10%. The sheer physical size of *Intelsat IV* is quite surprising, being nearly 8 ft diameter, and standing over 22 ft high. The electronics is all solid-state, apart from the output stage of each transponder, which is a travelling-wave tube. Design life is 7 years, including the capability of switching t.w.t.s on ground command.

There are currently 111 Earth stations receiving signals from four active *Intelsat IV* satellites.³ These stations are normally a 97 ft diameter dish weighing 315 tons, with a cryogenically cooled pre-amplifier. Reception of the faint signals depends more on the quietness of space as a background than on a brute force signal strength.

Nevertheless, the next technical development in this field is likely to be the advent of the direct broadcast satellite, with a radiated power measured in hundreds of kilowatts, giving direct reception to a domestic television receiver having a man-transportable aerial, without the intermediary of a Goonhilly Down aerial feeding a BBC relay. Time will show to what use the politicians will put this imminent electronic break-through. India and Brazil are already interested in its educational possibilities. This type of satellite also offers the possibility of reception in difficult areas, including secluded valleys and other out-of-the-way places; with it the developed countries could provide an educational service to the developing countries, teaching them to read and write, followed by agriculture, medicine including birth control, etc. Personally, I hope for the latter, and that the language taught should be English, and to this end we should offer very active collaboration to the Americans.

Turning away from Comsats, it seems to me that the public acceptance of radio communication over millions of miles has been remarkable. Few people other than DX hounds and amateurs have ever tuned in a transmission more distant than Radio Luxembourg. These same people accept television transmissions from the Moon, Mars and Mercury as though it were commonplace and to be expected. Sir Bernard Lovell had no such easy illusion when he was asked to use his large dish antenna to keep contact with a partially disabled Venus probe, suffering from reduced signal strength. Each evening he would give the command to transmit the 'switch on' signal, knowing that one evening the satellite would not respond. He would then have to wait 5, 6 or even 7 agonizing minutes while the signal went across space at the speed of light, before knowing if success had again been achieved. This is a clear illustration of relativity, and the ambiguous meaning of 'simultaneous', on a scale which the human can appreciate without instrumentation.

This leads me to forecast what I believe will be considered to be the greatest discovery of our Twentieth Century, surpassing even the aeroplane, radio, television, jet propulsion, nuclear power, transistor or laser beam. I refer to Communication with Extra-Terrestrial Intelligence, CETI for short. There are now annual sessions on the subject, and since 1971 the Russians have

been spending tens of millions of pounds on listening and correlating signals received on 600, 1000, 1875, 3750 and 10 000 MHz, from the periphery of their vast country, with stations up to 5000 miles apart, to eliminate signals emanating from Earth. So far there has been no very definite positive result announced, although some interesting non-terrestrial signals are still being analysed.

The other great space power, USA, has not been content merely to listen for CETI signals, but when the mighty 1000 ft dish aerial at Arecibo was reopened on 16th November 1974, an intense narrow beam signal from a 450 kW transmitter was directed at Messier 13, where on arrival it should be the strongest radio object in the Galaxy.

Several space probes are already flying past the Sun's outer planets, and these will ultimately travel on into outer space, far outside the space dominated by the gravity of our Sun; they all carry written messages 'to whom it may concern'. It will not be long before genuine interstellar flights are launched from Earth, directed at specific stars, and merely flying close to Jupiter to get gravity assistance to reduce the journey time. We should begin to formulate our ideas on the electronic equipment needed to cope with the possibility of such probes encountering extra-terrestrial intelligence, as so much time would be wasted if the probe had to signal back several light-years and then await further instructions. Clearly the probe should provide for all reasonable eventualities. In designing such equipment we need only deal with lower intelligence; an encounter with equals is statistically unlikely, and superior intelligence will take the initiative anyway. If our interstellar probes encounter inferior intelligence, we should want to place an alarm to be triggered many years later, when the alien technology achieves a particular break-through. This alarm should not be situated on an inhabited planet, where it could be abused, but well-marked on a neighbouring moon, or placed in a gravitationally stabilized orbit, 60° ahead of or behind a moon, where no fuel would be required over the millennia for station-keeping purposes. Solar cells might well provide a small amount of power for detection devices, and run for thousands of years, or even indefinitely, but the alarm itself would require many kilowatts, rather than watts of power, which would probably have to be stored as separate chemicals until triggered (perhaps a lead-acid or hydrogen peroxide fuel cell).

If the alarm is to be sent back to Earth secretly, a large attitude controlled dish will be required, which would be quite liable not to lock on to the Earth after such a time lapse. Anyway, such a dish would be easily detected by the growing alien intelligence, so perhaps a better choice is to re-transmit a delayed omni-directional signal at the same frequency as the coherent radio signals which first activated the detector, and to send a message for the alien intelligence to decode. It may be argued that radio is not the only manifestation of intelligence readily detected at a distance; for example, atomic explosions or digging up our probe placed in a well-marked position on a nearby moon are equally easy to detect. However, these alternatives are more likely to be triggered by unintelligent natural events.

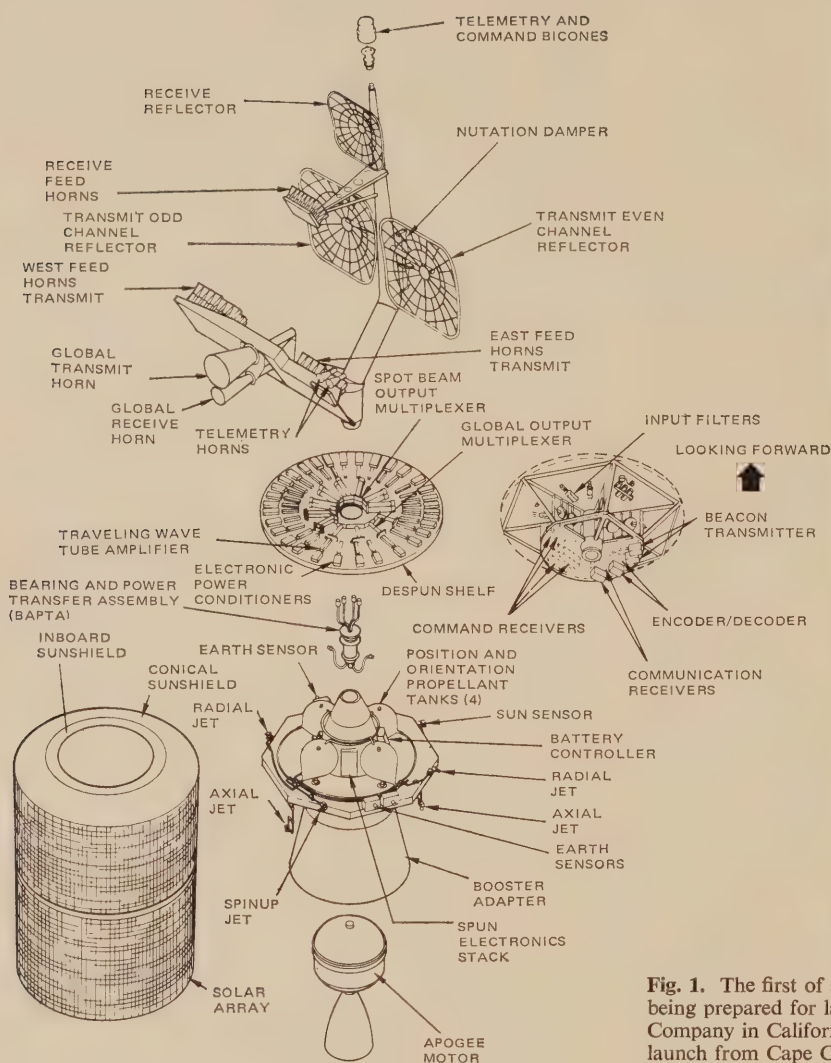


Fig. 1. The first of six *Intelsat IV-A* communications satellites being prepared for launch by engineers of the Hughes Aircraft Company in California. It was placed over the Atlantic following launch from Cape Canaveral, Florida on 25th September, 1975.

Before I venture any further, I am well aware that much of these latter paragraphs will look like 'sci-fi' to many of my contemporaries in the IERE, and even more to those outside. I wonder why we in Britain take such a special pride in ignoring space? Currently Europe (without US participation) is excitedly designing and building an inhabited orbital workshop called *Spacelab*, some 60 feet long by 15 feet diameter. The British share is to design and fabricate the pallets on which the equipment will be mounted. This is history now, and cannot be changed, but looking ahead, I am confident that the first electronic contracts for an interstellar probe aimed specifically at the nearer stars will be let in the coming decade. The probe will need the usual navigational, Earth communications and scientific equipment, typical of say the extremely successful *Mariner* series of planetary probes, but will have to be supplemented by devices to detect alien planets and moons, compute their orbits, select targets, and then calculate and activate probe trajectories to orbit or to land on these targets, coupled with CETI equipment to cover all eventualities of alien life.

One thing is certain. If CETI can be shown to exist, it will lead to an explosion of human knowledge transcending even the Industrial Revolution in its effects upon mankind, and our own Institution is directly concerned with one of the main disciplines involved.⁴

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Whither Data-processing?

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Data-processing applications are rapidly becoming too complex to be supported by current computer architectures. A new type of machine structure, based on parallel associative processing and array principles, is proposed to overcome the limitations of attempting to map a non-numerical problem on to a numerically-orientated machine. This approach could lead to hyper-high-level languages and perhaps contribute to the solution of the 'combinatorial explosion' problem.

'Everyone knew how laborious the usual Method is of attaining to Arts and Sciences; whereas by his contrivance, the most ignorant Person at a reasonable Charge, and with a little bodily Labour, may write Books in Philosophy, Poetry, Politicks, Law, Mathematicks and Theology, without the least Assistance from Genius or Study.'

JONATHAN SWIFT¹

Digital computers are being extensively used for such purposes as the retrieval of information from large databases, simulation studies, air and road traffic control etc., where essentially non-numerical data is being processed to derive information about the real world. There is every indication that these applications will continue to grow at a rapid rate in the future.

Unfortunately the conventional digital computer is inept and clumsy when called upon to perform non-numerical processing. Starting with Babbage's original concept of an 'analytical engine', Von Neumann, and many others after him,² have transformed the idea into the sophisticated artefact that it is today. But, although these machines are technologically many orders of magnitude more accomplished than Babbage's original engine, for example in terms of speed, size and reliability, they are nevertheless still basically fast electronic calculating machines. Indeed the original specification for a stored program computer was conceived specifically to process computational algorithms. Von Neumann's formal definition of an automatic digital computing system³ as 'a (usually highly composite) device which can carry out instructions to perform calculations of a considerable order of complexity—e.g. to solve a non-linear differential equation in 2 or 3 independent variables numerically', illustrate the tenet of this argument.

Professor Douglas Lewin (Fellow 1974, Member 1960) has been at Brunel University since January 1972, initially as Professor of Digital Processes, and since 1974 as Head of the Department of Electrical Engineering and Electronics. He was previously a Senior Lecturer in the Department of Electronics at the University of Southampton and from 1962 to 1967 he lectured in Computer Engineering at Brunel University. He has served as a member of the Southern Section Committee and has been a member of the Computer Group Committee since 1970 (Chairman since 1974) and of the Papers Committee since 1971; he has represented the Institution on the organizing committees for several joint conferences. In 1973 Professor Lewin was elected a member of the Council. He has contributed papers to the *Journal* and is author of several books and Editor of the journal *Digital Processes*.

As a consequence, computers are grossly inefficient when applied to problems which require the processing of data represented in symbolic, rather than numerical format. Typical application areas which give rise to these problems are information retrieval, pattern recognition, language translation (both natural and artificial), automatic software generation, and the machine intelligence area generally.

Although it is always possible of course to perform non-numerical processing using a conventional digital computer, it can only be done by using software to emulate a more sophisticated data-processing machine. In the majority of cases these systems are difficult and expensive to realize (software development costs alone being quite phenomenal) evidenced by the fact that systems of this type are often late in delivery and in many cases, still contain logical faults even after final installation has taken place. More important perhaps is that in some cases, for instance natural language translation, the problems are still economically intractable. It would be true to say in this context that the original sin of computers is that they compute!

From another viewpoint, if we examine the technical forecasts that were being made in the 'fifties for the future of computers (and are still being made⁴), we find that most of these predictions remain unfulfilled. Many of the applications suggested at that time, such as speech and character recognition systems, language translation, learning machines, centralized data banks and retrieval systems, home computer terminals etc., are still under active development, and what systems do exist are far from being generally available.

The major reason for this unhappy state of affairs, apart from the obvious one of the sheer complexity of the system, is that computers due to their primitive calculating nature, are still far too difficult to program. Moreover, although we have experienced a continuing reduction in the cost of hardware (particularly processing hardware), programming costs, due to the human factor, have been increasing at a slow, but constant, rate. This situation still persists, even in the current honeymoon period, with microprocessors. The only thing wrong with micro-processor systems is that you have to program them—normally at a much lower micro-order level.

High level programming languages, such as ALGOL 68, PL/1, LISP, SNOBOL IV, CORAL 66 etc., provide a means of simplifying and reducing the amount of effort required to produce software.

Unhappily high-level languages have not been a universal success. In the first instance, in many non-numerical applications, an efficient implementation using these languages is not possible and it is necessary to resort back to assembly language. This is due almost entirely to the difficulty of mapping a symbol data processing structure onto a fundamentally unsympathetic hardware configuration.

Secondly, there are too many programming languages—it is often easier to conceive a new language than undergo the disciplines imposed by an existing one. The result is the present 'Tower of Babel'—programming languages are tending to change from a means of communication to a cult of isolation. In fact we are in danger of breeding a new technocracy based on a sub-culture of FORTRAN, ALGOL, and operating systems jargon. This unhappy state of affairs was perhaps foreseen by Lewis Carroll:⁵ " . . . When I use a word", Humpty Dumpty said, in rather a scornful tone, "it means just what I choose it to mean—neither more nor less". It is imperative if progress in computer applications is to be accelerated, or even maintained, to develop data processing systems which are easy to program and simple to use. Current programming languages require the user to specify exactly the algorithmic solution to a particular problem, what is required is a problem-solving language which enables the user to specify a problem and a possible means of solution.

Another contributing factor to the current computer dilemma is the dichotomy that still persists between software and hardware designers. Computer systems engineering, with the emphasis on *engineering*, must be seen as a combined integrated technology embracing both hardware and software techniques. In addition the lack of a suitable design methodology, which would enable complex systems to be specified and evaluated prior to implementation, is a major handicap—but that's another saga!

It is interesting to reflect however, if any other branch of professional engineering could supply complex systems which were only partially (and very often inadequately) specified, untried and untested before installation and with a high probability of failure in operation—and still retain its integrity!

Though considerable work is being done on formal methods of programming, such as Dijkstra's work on structured programs⁶, it is still related to conventional computer structures. What is really required is to go back to fundamentals and redefine a machine which is specifically orientated towards data-processing, at the symbol and bit level, rather than numerical computation. It will be obvious that a special-purpose computer for data-processing will be inefficient when performing arithmetic operations (which is the inverse of the present situation), however there are more than sufficient applications to justify such a machine.

Digital computers are based on the stored program principle of Von Neumann⁷ and consist essentially of a store, for holding program instructions and data, a control unit for decoding and executing instructions, an arithmetic and logic unit for processing data, and an

input/output unit. The normal sequence of operations is that instructions are read down from the store to the control unit where they are decoded and an execution sequence initiated. When required, depending on the instruction being executed, operands are extracted from the store and processed in the arithmetic and logic unit under the supervision of the control unit; the results being placed back in the store. The function of the input/output unit is to provide communication channels to the outside world for programs and data.

The main store of the computer is a vital component and may be considered as a nest of pigeon-holes, or post-boxes, each capable of holding a computer word which may be used to represent either an instruction or an operand. Individual locations are identified by using a contiguous addressing scheme, with a unique address being allocated to each location. Stored information is accessed by explicitly stating or generating the actual address of the location containing the data that are required. This can, and does, lead to difficulties, since the programmer (or the operating system) must always keep a record of where the data are stored, or the appropriate route for obtaining it.

The concept of memory is a fundamental one, relevant to both computing machinery and the human brain. Charles Babbage⁸ is quoted as saying 'If memory be absolutely destroyed, our personal identity is lost', which is as true for the computer (where the memory holds the program instructions) as it is for human beings. Recent experimental work in psychology suggests that the human memory is organized in an associative fashion using a form of tree or list-structure in order to achieve the required hierarchical relationships. A simple proof of this is the way we intuitively re-arrange complex activities, such as information retrieval, management organization, etc., into hierarchical control structures.

In fact the very language we speak can be represented by a tree structure, generated by a phase structured or transformational grammar. It is also relevant to note that Chomsky⁹ has postulated the existence of a universal grammar which may well be genetically endowed. Moreover, we normally communicate in a sequential manner, using character strings of variable lengths (sentences) with a syntactic structure (the grammar) which enables us to obtain a semantic interpretation of the messages.

Thus, there would appear to be a fundamental incompatibility between the human being and the computer in the methods used for communication and storage of information. In addition, since the computer is basically a fast calculating machine, all problems must be construed as numerical procedures; few human beings are numerate to this extent. It is thus easy to understand the difficulties that can arise when programming a computer to perform anything other than established computational routines. In order to compensate for this mismatch it is necessary to create a vast software interface between the user and the embryonic central processor which attempts to emulate the data structures of the mind, and the processes required to recall and manipulate stored data.

Many computational procedures could be simplified if storage locations could be accessed by the actual data held in the location itself, rather than by their absolute address in the store. This is the basic principle of the content addressable store, in which storage locations are addressed by specifying their contents, or some selected parts of it. The result of the content addressing operation can either be the absolute address of the corresponding storage location or, in the case of associative addressing, the actual argument, or data, associated with the description address.

As a simple example of the type of operations that are required in a data processing environment let us consider the biographical record:

BRUNEL I. K.; SEX = MALE; BORN = 1806; DIED = 1859;
PROFESSION = ENGINEER

which might occur as one entry in an information retrieval system. Note that the entry is essentially a symbol string with the structure of a name followed by an argument (or arguments) listing the various attributes associated with the name. As with normal English, punctuation is necessary to prelimit and delimit the structure and to separate the name-argument pairs. A biographical entry of this type contains the answer to many questions, and providing the questions to be asked are all of the same type (and of course known beforehand), it is relatively easy (but not necessarily efficient) to program a conventional computer to perform the required retrieval operations. For instance, to extract Brunel's profession the data-base must be accessed using the keys BRUNEL, followed by PROFESSION (both suitably encoded to provide absolute addresses) to isolate the required information. This type of search procedure, known as direct retrieval, may be readily programmed using established software techniques such as hash-tables, inverted files, etc. However if the answer is required to questions of the type 'How many engineers were born in 1806?' it is necessary to search the entire data-base looking for the date 1806 and when a relevant entry is found it is then necessary to establish if the recorded profession is that of engineer. This cross-retrieval mode of search (using the argument rather than the name as the key), proves very difficult and time-consuming when implemented using conventional software procedures. An obvious solution to this search problem would be to use associative addressing, which would allow all records to be accessed directly with the keys, 1806 and ENGINEER, to obtain the names (and possibly the number) of the required engineers.

Ideally it should be possible to pose questions of any type to a data-base, particularly in an information retrieval environment. However, current information retrieval systems impose considerable restrictions on the user which render them ineffectual for anything other than the most simple applications.

Computer structures based on associative memories have been described in the literature¹⁰ but as yet have not been fully exploited. The systems described fall into two categories, those employing a word-organized bit-parallel content addressable memory (operating with a fixed record length) in conjunction with a conventional mini-computer—the STARAN system^{11, 12}, and cellular

cascaded arrays with a variable record length^{13, 14}.

The STARAN system has been applied to air-traffic control and data-base management, but difficulty is being experienced in providing a suitable programming philosophy. This is due to the basic architecture which can only allow the associative memory to be treated as a programmable peripheral rather than as an integral part of a computer structure. On the other hand, the cellular array system, with its emphasis on distributed (but integral) memory and processing elements, is a more novel structure orientated to the storage and manipulation of character strings with a range of basic machine operations comparable to the functions found in the SNOBOL IV programming language. It is important to realize that the cost effectiveness of these systems depends on using the associative memory as a processing element and not as a primary means of storage.

There is every possibility that a machine of the parallel associative array type structure, being closer to the fundamental requirements of human data-processing, will enable a hyper-high-level computer language to be developed.

Other parallel array processors have been proposed, notably the *Illiac IV* system¹⁵ which utilizes 256 64-bit word processing elements, and the ICL array processor DAP¹⁶ which is based on the same principles but employs single-bit processors and uses modern l.s.i. technology. Both machines were originally conceived for 'number crunching' problems involving, for example, the evaluation of large matrices, however it is claimed that DAP is also suitable for non-numerical processing. An alternative approach is the distributed micro-processor system described by Dagless¹⁷ which comprises some sixteen microprocessors working via a common bus with a shared central storage system. Special-purpose array computers for pattern recognition, and image processing have also been described; in particular the adaptive logic array due to Alexander¹⁸ and the pattern recognition array developed by Duff¹⁹ seem to be major innovations in this area. All these machines however would appear to suffer from structurally inherent programming problems which require most applications to be programmed at the processor level or with the assistance of macros embedded in a conventional computer language.

Another important area of development is the replacement of software by hardware or firmware modules using micro-programming techniques. Though this approach produces a significant improvement over existing methods, for example, the GEC-Marconi-Elliott high-level interpretive machine for CORAL 66, it cannot effect a major breakthrough, for though efficiency is considerably improved, the basic structure of the machine remains unchanged.

Future data-processing systems will almost certainly consist of a dedicated array of processors, performing specific numerical and non-numerical tasks, connected together in a distributed network with access to a common data-base and with communication being provided by 'intelligent' terminals. The major problem that requires to be solved is how such a network is to be controlled

and programmed—perhaps by a general-purpose associative processor?

There is of course a major commercial drawback to developing a fundamentally new type of computer structure, and that is the considerable investment that already exists in software for conventional machines. However it is essential to investigate machines which are specifically orientated to non-numerical processing (and hopefully more compatible with human behaviour) with the twin objectives of increasing computing and programming efficiency. Thus, the vast amount of software which is required at present to endow a computer with even a rudimentary intelligence may be reduced to sensible proportions. It is quite possible that the answer to the 'combinatorial explosion', which Lighthill²⁰ considers to be the major obstacle to further progress in artificial intelligence, could well lie in the development of special-purpose machines of this type.

In conclusion it is perhaps worth pondering whether Society really needs new and more powerful computers? Are computers going to benefit mankind, assuring us a prosperous and challenging future, or are they going to produce an Orwellian existence? There is no doubt that technological progress must take place, as the consequences of non-participation in this activity could be far more disastrous than the supposed dangers. As to what the future may bring, it is not possible to better the words of Norbert Wiener:²¹

'On the other hand, the machine like the djinnee, which can learn and can make decisions on the basis of its learning, will in no way be obliged to make such decisions as we should have made, or will be acceptable to us. For the man who is not aware of this, to throw the problem of his responsibility on the machine, whether it can learn or not, is to cast his responsibility to the winds, and to find it coming back seated on the whirlwind.

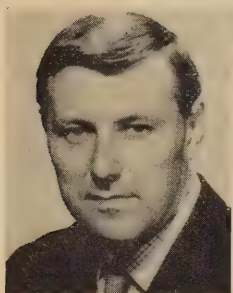
'The hour is very late, and the choice of good and evil knocks at our door'.

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New Horizons in Electronics

J. R. JAMES, B.Sc., Ph.D., F.I.M.A., C.Eng., F.I.E.R.E.

New topic areas in which the electronic engineer is being involved are noted and major advances in both component and large scale system design are highlighted. The spread of interest into seemingly unrelated fields, particularly those involving human sensory interfacing, is evident and both component and systems designers will become increasingly involved in inter-disciplinary approaches in the future.

Introduction

During the past fifty years the progress in electronics has been astronomical to say the least and the many personal accounts in this special Golden Jubilee issue bear this out. Just what the next half century holds in store is a matter for much speculation but there are many visible pointers to the future. It is perhaps fitting to conclude this issue with some general comments about the future development of electronics and with that intention in mind this essay focuses on some of the most pronounced trends and in particular those involving human senses and behaviour.

In the past, electronic engineers have often tried to delineate the boundaries between topic areas that have a high mathematical or physical content and those that deal with solely engineering aspects but standpoints have had to be perpetually revised to keep in step with the continual stream of new developments. The term 'light' electrical engineering, as opposed to 'heavy', was appropriate two decades ago but is now a totally inadequate classification and has fallen into disuse. In looking to the future one is aware that some present-day trends may well be shortlived but even so a good indication as to what is now reckoned to fall within the scope of electronics can be obtained from the recent international literature. Many of the topic areas overlap into other fields and are not exclusive to electronics; for instance computer-aided design algorithms, fibre optics and image processing are also presented in publications dealing specifically with computational software, applied physics or cognitive studies. Some of the new topics that are being drawn into the electronics fold may seem at first sight to have little relevance to electricity as for instance 'social systems engineering' recently featured in the literature.¹ We are however somewhat conditioned

to such enlightenment and topics like pattern recognition, optical processing, adaptive learning networks etc., which in previous years may have been dismissed as fringe subjects are now pursued in industrial and university electronics laboratories. In other areas it is electronics itself which has been annexed as a tool; medical electronics is one such example.

On scanning the literature it is apparent that electronic engineers are increasingly involved with the end-use of the equipment that they design; the designer is thus committed to studying an overall system of many component parts and quite often this embraces human sensoral parameters. Many of the new trends in electronics arise from the studies of the man/machine interface and it is thus appropriate in this essay to give particular attention to electronics system design. There have of course been major advances in the more traditional aspects of electronics concerning component and sub-assembly realization and optimization and these will be highlighted first.

Component and Sub-assemblies

Components, devices and sub-assemblies continue to shrink in size, decrease in weight, and improve in reliability and manufacturing costs move downwards; very detailed reviews of the present technological state-of-the-art have recently been given² and future trends predicted;⁸ the interested reader will find these references quite illuminating.

Magnetic bubble devices, liquid crystal displays, charge-coupled devices, glass fibre optical waveguides, and bipolar large-scale integrated circuits, are just a few of the modern building bricks that have revolutionized electronic instrumentation, communication systems, data links, computers, aerospace systems, etc. The packaging of integrated circuits is now so efficient that the physical size, production costs and operating costs of high density circuits are no longer limiting factors; this has led to the microprocessor concept whereby a small but powerful computing facility can, with appropriate interfacing, take over the functional role of many conventional components and sub-assemblies. A microprocessor not only physically resembles a small, medium-priced component but is beginning to be treated as one in the sense that its computational power need not be fully utilized in every application. This philosophy in turn encourages the evolution of very cheap and reliable standardized units. Several interesting articles⁹ have appeared which describe these phenomenal develop-

Dr. J. R. James (Fellow 1975, Member 1960, Graduate 1956) has been a member of the academic staff at the Royal Military College of Science since 1961. He has published widely on research and development work in the field of microwaves, antennas and speech processing, including papers in the Institution's Journal for one of which he received the Heinrich Hertz Premium for 1973, and he is currently working on electromagnetics and communication systems. Dr. James has been a member of the Papers Committee since 1970 and its Chairman since 1972; after completing a three-year period of service on the Council as a representative of the class of Members, he has been elected a Vice-President.

ments and explain why the microprocessor concept is the most significant development of late.

All these component developments follow the traditional theme: the realization of a linear or non-linear transfer function by some physical means and the subsequent optimization and engineering of the device. Looked at in this way the possibilities of alternative realizations should be boundless and there is some evidence to this effect. The investigations into organic semiconductors³ have now been under way for some years and may well lead to new concepts and possibly a major advance towards the self-repairing component. In another area experiments have been conducted on brain-like cells made from gold and iron wire together with nitric acid. The paper by this experimenter⁴ is most interesting and he puts forward many proposals for realizing logic circuits in a continuous bulk medium in order to increase the bit density. His ultimate aim is of course to create a volume of brain-like cells and the devices constructed so far are primitive cells. There is also a growing interest in discovering how insect and animal electromagnetic and ultrasonic sensory systems function since these appear to be highly optimized. Progress in these new areas of electronics is understandably slow but the significant step forward that should be noted is the increasing awareness that electronics need not be confined to conventional inorganic materials; the necessity for an interdisciplinary appreciation and approach is very evident.

Systems

The evolution within the area of interest of the electronic engineer of certain newly emerging topics that involve human sensory and behavioural aspects, is in itself of interest since it is not obvious why pattern recognition for instance has particular relevance to modern electronics. A few typical case histories can best illustrate the changing scene as follows.

The miniaturization of electronic components makes it feasible to conceal apparatus that detects the presence of an intruder within a building. It is easy to design a device that will detect a human being by monitoring the associated scattering of sound, light or radio waves but unfortunately the discrimination against other animals and extraneous moving scatterers is very poor. The situation can be improved somewhat by making the apparatus sensitive to particular behaviour patterns exhibited by humans and in particular intruders. This leads to the electronic exploitation of correlation and other signal processing techniques. Despite these refinements the false alarm rate can be irritatingly high and the search for improved designs is seen as a distinct challenge. These difficulties are to be expected however if the equipment specification is re-phrased to reflect the aim more precisely; i.e. for a cost of a few tens of pounds can we create an electronic system that has intruder detection capabilities comparable to that of a trained security guard? Looked at in this way it follows that the equipment could emulate the human being and extract from the scene the relevant information; the study of how a human being recognizes intruders is thus an appropriate task for the equipment designer and is just one example of

what is more generally known as pattern recognition. For an up-to-date survey on pattern recognition the reader is referred to Kanal.⁵

In the past high standards of voice reproduction were aimed at and generally obtained in radio transmission. The electrical constraints now imposed by the complexity of modern transport and military requirements have presented the radio engineer with the problem of providing only adequate voice production in the operational environment. In the aircraft case for instance, mechanical vibration, cockpit noise, flight fatigue, stress, personal considerations etc., are some of the many factors which determine whether the voice reproduction is adequate to convey the intrinsic information. Clearly none of these factors can be ignored and in practice design criteria are extracted from intelligibility tests carried out in the operational environment. The multitude of effects involved can be studied in isolation under the topic areas of psychology, ergonomics, pattern recognition, information theory, propagation etc., but it has become the custom to refer generally to the designer of such a system as a systems engineer.

Next consider the video phone which provides a telephone subscriber with both the voice and image of the person he or she is in conversation with; when satisfactorily developed this innovation could obviate the need for much present-day routine travel. At present the allocated bandwidth is relatively narrow and picture quality is necessarily restricted, hence it is important to investigate what image information must be preserved for acceptable social or business activity; also subjective properties such as charisma, presence, confidence etc. which often justify personal contact, are some of the parameters that have to be considered if the video phone is to be widely adopted.

The final example concerns the installation of a modern communication network in a region where people's lives have followed the same life style for years. For economic reasons the network must allow for a growth in communication traffic but this in turn depends on how the installation affects the life style of the community. Here we have a real-time global system embracing both people and equipment and the need arises to quantify the complex sociological effects.

It is important to appreciate that the involvement of the electronic engineer into these other fields has arisen in the main from necessity; an ineffective intruder alarm or misrepresentative video phone or an unintelligible aircraft communication system is as unacceptable as a simple electronic component that fails to meet its specification. Likewise a communication network that is saturated by impatient users at an early stage creates enormous problems of confidence and the financial viability can be eventually impaired, thus undermining the project as much as faulty components. Sociological factors in engineering have often been overlooked in the past at some cost, i.e. the effect of high-rise dwellings on peoples' behaviour and the subsequent repercussion on civil engineering; it now seems that electronic engineers have recognized the need for some related studies.¹ Could it be that electronic engineers with their trained

mathematical minds will be able to put some aspects of sociology on a firm analytical basis? Readers who have views on this topic should certainly read the recent articles in the electronics literature.¹

The Changing Scene

Resistors, capacitors, inductors and transistors were for many years the building bricks of electronics but in the new era of large scale integrated circuits the basic element can itself be a complex configuration of thousands of elemental components. With such a high degree of circuit sophistication at his disposal the engineer is freer to experiment with large-scale systems.

There are large-scale systems such as data links, computers, automatic instrumentation and production testing, etc. which can be confined initially to the study and optimization of electrical parameters but human factors invariably emerge if the system considerations are extensive. In general interdisciplinary teams are now required for both the research and development of large systems; particular attention has been focused on how best to carry out telecommunication research in universities.⁶ The management of systems projects is particularly demanding and has opened up new career opportunities. By comparison component design can seem very straightforward and there has been a tendency to associate a higher status with systems work. However it is now generally realized that components, sub-assemblies and system design cannot be viewed independently; they are inter-related and equally important. In fact in many systems studies it is found that the size or weight or reliability etc. of a particular component is inadequate and the system viability depends critically on improved component design. For instance the antenna is commonly now the most cumbersome and critical component in a modern communication system which has been considerably miniaturized by l.s.i. techniques.

Improvements in component design manifest themselves in some way or other in improved system performance, hence component research is usually cost effective in the long term. Research into some of the newer areas for the electronic engineer is not viewed in the same favourable light and severe criticism has been made of some aspects of speech recognition research.⁷ Kanal⁵ says that the question 'What is a pattern that a machine may know it, and a machine that it may know a pattern' remains essentially unanswered after two decades of research. The slow rate of progress so far may be due to the present-day constrained approach. Suppose for instance that the workings of a computer complex were to be probed and formulated but only access to the peripheral terminal equipment was permitted. It seems doubtful if either the unique physical realization or some positive guide as to how to simulate the workings of the machine would result. If we apply this reasoning to the investigation and simulation of human sensory functions, it seems logical that physiological investigation into brain cell behaviour etc., will yield more significant information than abstract mathematical formulation, at least in the early stages. Cost effectiveness in this type of research may well be radically

improved by selecting specialists with wide interdisciplinary interests.

The Future

As to the future there can be little doubt that the present-day interest in studying the overall behaviour of a system of components will be maintained; furthermore the need to embrace human sensory behaviour within certain systems is if anything likely to become more apparent. Component and sub-assembly designers will not necessarily be preoccupied with conventional physical realizations. Aspects of biology, physiology etc., have already been encountered; systems studies already embrace many other disciplines such as psychology, perception and sociology, and even some aspects of marketing are now considered relevant. It is widely understood today that the boundaries between the various scientific fields are becoming less distinct and in that sense the interdisciplinary trends in electronics are to be expected; it is likely that all future electronics specialists will need to acquire a broadly-based training or appreciation at some time during their career. Industrial and Government laboratories will probably concentrate more on the systems aspects while universities may, through lack of large-scale facilities and supporting teams, continue with much of the narrower specialist work as is the present trend.

Finally the learned institutions can do much to provide a sound base for the expansion of electronics into interdisciplinary fields of activity. The Institution of Electronic and Radio Engineers has in the past focused attention specifically on the needs of the professional electronic engineer and is now well poised to respond to the continued diversification of electronics. Whether the word 'electronics' continues in future to represent such an expanse of topics is debatable but the fact remains that for the searching and inventive mind the horizon in both components and systems design presents unlimited challenge and opportunity.

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IERE

News and Commentary

National Electronics Review

The four issues of *National Electronics Review* published so far this year cover a broad range of subjects, mostly but not wholly following its editorial aim of describing the impact of electronics on society.

The National Electronics Council has actively encouraged for some years the introduction of electronics into the curricula of the British secondary school system as an academic subject, capitalizing on a hobby interest. Two schemes have been sponsored, namely the initiation of the teaching of Electronics Systems as an A-level subject; complementarily to this the Electronics Link Scheme which provides technical expertise from industry to encourage project work, has been inaugurated and a two-part article (January-February and March-April 1975) discusses present progress and future plans in these two projects.

At the end of 1974 the Council set up a working party to prepare a submission for the Committee of enquiry on the Future of Broadcasting and the May-June issue presents the report in full. The Council is clearly in a favourable position to draw upon authoritative assistance in providing evidence which will deal with both the programming and technological requirements of broadcasting.

A lengthy extract is published in July/August of Sir Ieuan Maddock's Royal Society Technology Lecture in which, under the heading of 'End of the glamorous adventure?' he calls for a more realistic approach to the allocation of funds for research and development, suggesting that these should go to 'the industries from which we earn our keep' rather than almost entirely to the so-called science-based industries.

The two regular features of *National Electronics Review*, the Company Profile and 'Electronics research in British Commonwealth universities' continue and under the former heading articles have been published dealing with the GEC Hirst Research Centre, the British Aircraft Corporation, Sinclair Radionics and GEC-Marconi Electronics.

Three UK University departments of electronic and electrical engineering have described their current electronics research—Birmingham, Bristol and Aston in Birmingham—and the fourth article (in March-April) came from the University of Auckland. More directly technological articles have appeared this year, notably 'Battery power for electronic applications', 'Skynet II—UK space success' while an article on electronic training in the Corps of Royal Electrical and Mechanical Engineers dealt briefly with the present work of the School of Electronic Engineering, REME, Arborfield.

Members of the IERE may subscribe to *National Electronics Review* at the special rate of £2.75; the normal subscription rate is £4 per year.

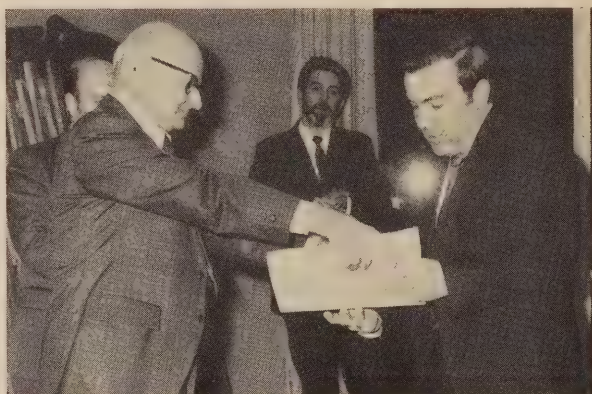
Service of Thanksgiving

In celebration of the Institution's Golden Jubilee a Service of Thanksgiving, of a non-liturgical nature, will take place on Thursday, 20th November, at 6.30 p.m. in the Church of St. Clement Danes in The Strand. (Please note change of time from original announcement.)

Tickets of admission will be sent to interested members on application to: Mr. G. D. Clifford, C.M.G., C.Eng., F.I.E.R.E., F.C.I.S., 9 Bedford Square, London WC1B 3RG.

Membership Certificate Presentations at Kent Section's Annual General Meeting

The formal proceedings of the Annual General Meeting of the Kent Section, held at Gravesend in April last, were supplemented by an informal ceremony at which newly elected members received their certificates of membership. The accompanying photograph shows Mr. Harvey F. Schwarz, C.B.E., a past President of the Institution, handing to Mr. Peter G. Willmott the certificate which confirms his election as a Member of the Institution.



In the background is Mr. Allan Prior, chairman of the Section from 1972-1975. He handed over this office at the A.G.M. to Mr. Eric Middlemiss, formerly the Honorary Secretary.

The meeting was followed by a lecture on 'The Application of Digital Computers to Radar and Navigation at Sea' by Mr. Bruce Williams, of I.B.M. (UK) Ltd.

A Service for Members—The Institution's BUPA Group

Private medical treatment is more in demand in the United Kingdom now than it was twenty-seven years ago when the National Health Service was started. More and more patients are prepared to pay for the right to be seen and treated by the consultant of their choice at a time suited to their business and domestic commitments. More and more people want privacy when they are sick.

The demand has risen, but so has the cost. Most people find that a subscription to BUPA—the British United Provident Association—is the most economical way to pay for the kind of treatment they would like.

Over two-thirds of BUPA subscribers join through Group Schemes and the Institution sponsors a BUPA Group for the benefit of members. Through this Group, members are eligible for a reduction of 10% on the basic rate of subscription and immediate entitlement to benefit upon acceptance of the registration instead of the customary waiting period of three months. If they are employers, then Company

Groups can be arranged at even more favourable rates of discount.

The cover offered by the BUPA Scheme consists of the cost of a private hospital bed (for 52 weeks per year), the cost of home nursing (for 26 weeks per year), the charges made by specialists for operations, consultations, pathology, radiology, radiotherapy and physiotherapy, the fees for regular attendance by a consultant physician in hospital, and for out-patient treatment. Wives, husbands and children of subscribers can be protected in the same way at a modest additional cost. The charge for the first child covers all subsequent children as well, up to the age of 18. After this age children can become BUPA subscribers in their own right with a lifetime discount on their own subscriptions, or alternatively opt for special student cover.

Existing BUPA subscribers are reminded that they should check that their level of cover is adequate for the level of charges being made in their own area. Rising hospital charges may well mean that in the event of having to make a claim a subscriber could find himself badly underinsured.

If you would like more information, please contact BUPA at 24 Newport Road, Cardiff, mentioning that you are a member of the Institution.

International Conference on Automobile Electronics

The next five years will surely see the development of a whole new range of electronic systems for the control of the vital functions of the car, possibly leading eventually to the use of centralized electronic control for mass production vehicles. The forthcoming international conference on 'Automobile Electronics' aims to review and discuss the current status and future developments expected in the application of electronics to automobiles, including the areas of traffic control, transmission and reception of traffic information and vehicle diagnostics, both from a financial and technological standpoint.

Topics expected to be covered include the following:

- Environmental requirements for automobile electronics
- Reliability experience with automobile electronics
- Transducers and actuators for use with vehicle electronic systems
- Ignition and timing systems
- Fuel control—emission control, fuel consumption control (including fuel injection electronic carburettors, ultrasonic atomisers, etc.)
- Anti-lock braking
- Safety related systems

Contributions are invited for this conference which is being organized by the Institution of Electrical Engineers (IEE) with the association of the IERE, the Institution of Mechanical Engineers and the Society of Automotive Engineers (USA). The IERE representative on the Organizing Committee is Mr. D. R. Ollington (Fellow).

The conference will take place at the IEE, Savoy Place, London, between 5th and 8th July 1976. Contributions of not more than 3,200 words (or less if illustrations are included) will be considered for inclusion in the conference programme. Those intending to make an offer should submit a 250-word synopsis immediately to the IEE Conference Department, Savoy Place, London WC2R 0BL, from whom further information will be available nearer the date of the conference.

Cenelec Approval for UK Manufacturer

The first certificate of manufacturing approval in the UK under the European CENELEC harmonized system of quality assessment for electronic components has been granted to Plessey Resistors of Swindon.

Approvals under this system will gradually replace those of the present BS 9000 system in the UK. The British Standards Institution is the UK national authorized institution and member of CECC. The agent of BSI, acting as the National Supervisory Inspectorate, is the Electronic Quality Assurance Directorate of the Ministry of Defence which is a full member of the European Electronic Components Quality Assurance Committee (ECQAC).

IEE-IERE Proceedings—India

The principal contents of recent issues have included the following:

Volume 12, No. 6, November-December 1974

'Surface wave characteristics of a lossy dielectric-coated conductor immersed in a lossy dielectric medium.'

Miss G. John, Mrs. R. Chatterjee and S. K. Chatterjee

'Design of a sure-start class C squarewave inverter with overload protection'

Mrs. L. C. Manoharan and S. Neelakantan

'Respirator design'

S. V. Saxena, P. Mukhopadhyay and H. K. Verma

Volume 13, No. 1, January-February 1975

'Dielectric hemisphere on cone antenna excited in the unsymmetric hybrid mode at microwave frequencies'

Mrs. R. Chatterjee and T. S. Vedavathy

'Synthesis of a spatial filter by using multiplexing technique'

R. S. Kasana and V. P. Bhatnagar

Volume 13, No. 2, March-April 1975

'Design of magnetic recording and playback amplifiers'

S. L. Sah and M. R. Kapoor

'Design and development of a lab-model silicon epitaxial reactor'

K. S. Balain, P. D. Vyas and B. B. Dixit

'Optimal signal processing'

B. V. Rao and S. H. Kajji

Volume 13, No. 3, May-June 1975

'Some characteristics of the Legendre filters'

S. Prasad and F. A. Hinchey

'Surface wave characteristics of the overmoded dielectric rods'

Miss J. Dilli, Mrs. R. Chatterjee and S. K. Chatterjee

Volume 13, No. 4, July-August 1975

'Radiation resistance of the travelling wave non-planar dipole antenna by the method of moments'

P. S. Bhatnagar and P. K. Chaturvedi

'A review of mathematical operations by optical data processing'

R. S. Kasana, G. P. Bhatnagar and M. C. Dubey

Correction

The following correction should be made in the paper 'Limitations of radar techniques for the detection of small surface targets in clutter' published in Vol. 45, No. 8, August 1975 of *The Radio and Electronic Engineer*.

Page 387, Fig. 15: photographs (a) and (b) should be interchanged.

Recent Developments in High-Quality Sound

London, 28th May 1975

Organized by the Institution's Communications Group.

Guest chairman, Mr. J. Moir

The first paper in this very successful colloquium was by P. A. Laven and D. Vinnell (BBC) on 'Stereophonic Broadcast Coverage in the UK', in which they discussed the use by the BBC of p.c.m. for distribution of stereo to the transmitters. The greater sensitivity of stereo to noise and other forms of interference was stressed and, whilst field-strengths of 50 $\mu\text{V/m}$ might prove satisfactory for mono, 250 $\mu\text{V/m}$ would be required for stereo. The CCIR recommendation was 500 $\mu\text{V/m}$, and the use of a better receiving aerial for stereo may often be required.

Adjacent and co-channel interference proves to be the major source of interference to stereo reception, and the performance of many receivers is dramatically worse than when receiving mono. The original plan for national coverage of mono was based on a nominal spacing of 200 kHz between channels, but 50 and 100 kHz offsets have proved to be necessary. Such offset channel frequencies reduce interference to mono, but now prove to be an important source of stereo interference, and a tape demonstration showed the results of interference for 50 and 100 kHz offsets with various protection ratios. It was noted that Rennes in France was 50 kHz offset from a UK Radio 4 transmitter with which it interferes, and this shows that the problem of offset requires a solution at international planning level.

The discussion covered such subjects as possible widening of the Band to 104 or 108 MHz to ease the channel spacing problem, clearing non-broadcasting channels from the Band, effects of polarization changes during propagation, and possible single-sideband reception.

A paper by D. W. Osborne (BBC) followed on 'Digital Links for High Quality Sound Signals'. He posed the question 'Why digits for sound?', and showed the advantages of accuracy, stability, noise-resistance and a long m.t.b.f.

The price to be paid was the need for a wide bandwidth. The Nyquist requirement for the minimum sampling rate was met with a rate of 32 kHz, which has the advantage of being a multiple of the 8 kHz rate used by the Post Office. The first BBC application was in television, where 'sound-in-synce' is used for distribution of the sound channel for vision, and it has now been extended to the f.m. service with 13 multiplexed channels. 13 bits per sample results in a signal/noise ratio of 72 dB, but the inclusion of a 14th bit provides for error protection, as was very convincingly demonstrated.

Various methods of bit-rate reduction were described. Instantaneous companding, already used for telephony, was useful but 'near-instantaneous' which follows a particular companding law, was found to be of greater value. The number of bits per sample can be reduced from 13 to a mean

of about 10, whilst retaining a quality similar to that of a 13-bit linearly-coded system. A demonstration showed the advantages of the system, a six-channel version of which is under development by the BBC.

Discussion followed on the use of limiting by the use of a delay-line to anticipate levels, and on signal attenuation in the digital domain.

In a paper entitled 'Dolby B-Type Noise Reduction for FM Broadcasting', K. G. Gundry (Dolby Labs) outlined the possibilities of noise reduction by companding and pre-emphasis. 'Masking' is a complex function of two sounds, but adjacent frequency regions are not masked. The Dolby A four-band system was outlined but the Dolby B, with frequency dependent variable pre-emphasis, was considered to have advantages for broadcasting. Spectral distribution of energy in broadcast programme material suggests that a lower pre-emphasis is possible (optimizing at 25 μs , i.e. +3 dB at 6 kHz). This would permit the mid-band modulation level to be raised. It was noted that over 100 US stations are using the system.

Discussion produced the obvious question; 'If there are over 100 users in the US, why is it not used in the UK?'. It was revealed that the BBC had conducted many tests, but were not yet convinced of the advantage to all their listeners. Mr. Gundry made the point that a change from the 75 μs US pre-emphasis to 25 μs was well worth-while, but a change from the UK 50 μs might not be so significant. A speaker raised a doubt by saying that 'single-ended' Dolby processing of a composite stereo signal would produce a degree of image-shifting.

Professor P. B. Fellgett (University of Reading) gave a paper on 'Methodology and Technology of Surround Sound', in which he pointed out that two-channel audio, which provided options for mono or stereo, can now be extended to include surround-sound, using four or more speakers. Engineering of surround-sound systems must reproduce an original sound field including its directional characteristics, and be capable of suitable encoding. Decoding must be conveniently capable of feeding the available number of speakers to reproduce the original field in the listening space. Limitations should not be imposed by the number of speakers in use, but they may be imposed by the number of channels available. Three channels will exhaust the capabilities of four speakers, and the addition of height information will require a minimum of three channels and six speakers.

Regarding the position of the listener, Professor Fellgett replied to a questioner that there was greater freedom than with stereo. He also considered that fundamental linear encoding was better than 'gain-riding' or other non-linear proposals.

R. V. Leedham (University of Bradford) gave a brief outline of his work in evaluation of the effects of concert halls etc. on recording and reproducing music. His paper on 'Time Delay Distortion of High Quality Sound and its Subjective Evaluation' concerned the weakest link in the chain: the loudspeaker. Initial tests showed that speakers with identical frequency responses could sound different. A programme of impulse testing showed differences in the phase characteristics—which is another way of referring to time delay distortion. Two impulses more than 100 ms apart would be heard as two separate events, but an interval of 1 ms would appear as a single event. Loudspeaker 'attack' is clearly affected by time-delay distortion.

A demonstration showed a technique for determining the subjective effects of amplitude and phase distortion by the use of a pulse and low-pass filter. The recordings were reduced in speed by ten times, and the speaker differences were heard

to be dramatically different. Noise tests were demonstrated, showing the effects on resonant and frequency-limited systems. Mr. Leedham concluded by indicating that further work remains to be carried out, and a computer modelling system has proved valuable in the work.

Contributions to the discussion questioned the validity of including a filter in the test system, but further work is being carried out on this point.

Angus MacKenzie (Audio Consultant) discussed 'The Present and Past History of Stereophonic Microphone Technique for use in Classical Music Recording'. An interesting presentation, amply illustrated by many recordings, ranged over the whole field of stereo recording. Commencing with the first stereo recording by Bell in 1932, the following demonstration of a Blumlein co-incident 'figure-of-eight' (1934) showed the superiority of this system over the spaced microphones used by Bell. There followed many examples of recording under various conditions, indicating that good recording is a combination of expertise, experience and a certain 'know-how'.

Mr. MacKenzie considered that concert hall architecture is largely 'luck' from the recording point of view, and expressed the opinion that the recording companies should make more of their recordings in the halls that are well-known for their recording characteristics. He demonstrated that, in some cases, a better recording could be made without the audience. In another demonstration, it was considered that the recording could be better than the performance heard in the hall. He concluded by playing an astonishingly bad record of German origin that had been on sale to the public. A final opinion was that, for good quality home entertainment, BBC concert broadcasts are superior to recordings.

A third BBC paper, on 'Properties of Hearing Related to Quadraphony and the Design of a Compatible 4-2-4- Matrix System', by D. J. Meares and P. A. Ratliff considered an investigation into a quad system suitable for broadcasting. It was stressed that, for broadcasting, a quad system is considerably simplified if the information can be compressed

into less than four channels. Further and above all other considerations, fully compatible mono and stereo services must be preserved.

Tests on inter-channel phase differences were described for anechoic and 'listening room' environments. Further tests were made on 'square array' reproduction to investigate localizing ability and crosstalk effects. The accuracy of the source in front and centre back can be localized to $\pm 3^\circ$. Side quadrants are not easily located, and level differences are found to vary from person to person.

The Research Department's 4-2-4 matrix on which further work is proceeding was described: greater inter-channel separation is required, and a two-channel system is being investigated, although more channels will provide better answers.

A lively discussion which followed emphasized the need for more knowledge of the hearing process.

The concluding paper by E. G. Trendell (EMI) on 'Quadraphony and Psychoacoustics' showed that there is a general lack of understanding as to how sounds, originating at the side or rear of a listener, are located. It is found that satisfying quad reproduction varies from person to person and with different types of music. It follows that some form of compromise is needed.

Pointing out that carrier systems, such as CD4 and UD4, must be cut at half speed, Mr. Trendell said this ruled out their commercial viability. Complementary channels for directional information can be of narrow bandwidth, while any quad recording must not have lower separation than stereo. The L-R separation is most important, and it is found that L_b and R_b can give an impression of L_r and R_r . Compressing four channels into two will lose information. 'Gain enhancement' and 'blend' systems can result in 'image flutter' whilst the logic is deciding the change of gain.

Reproduction tests have shown that ceiling height is significant. Multi-speaker units can differ from each other, depending on the positions of the speakers in the cluster. Headphones cannot produce an image in front of the head.

R. S. ROBERTS

United Kingdom Delegation to Geneva Conference

A United Kingdom delegation of 26 is attending the Low Frequency/Medium Frequency Conference at Geneva from 6th October to 22nd November. The delegation, which is led by Mr. Jolyon Dromgoole, Assistant Under-Secretary of State and Head of Broadcasting Department at the Home Office, includes representatives from the Foreign and Commonwealth Office, the British Broadcasting Corporation, the Independent Broadcasting Authority, the National Air Traffic Services and the British Radio Equipment Manufacturers Association.

The purpose of the conference, which covers the area of Regions 1 and 3 (Europe, Africa, the Mediterranean, Australasia, Asia and Russia) is to replan the use of l.f. and m.f. broadcasting bands to reduce mutual interference and facilitate further development. The conference, which follows on a preliminary technical conference held last October, is held under the auspices of the International Telecommunication Union.

The Conference has the task of allocating frequencies on

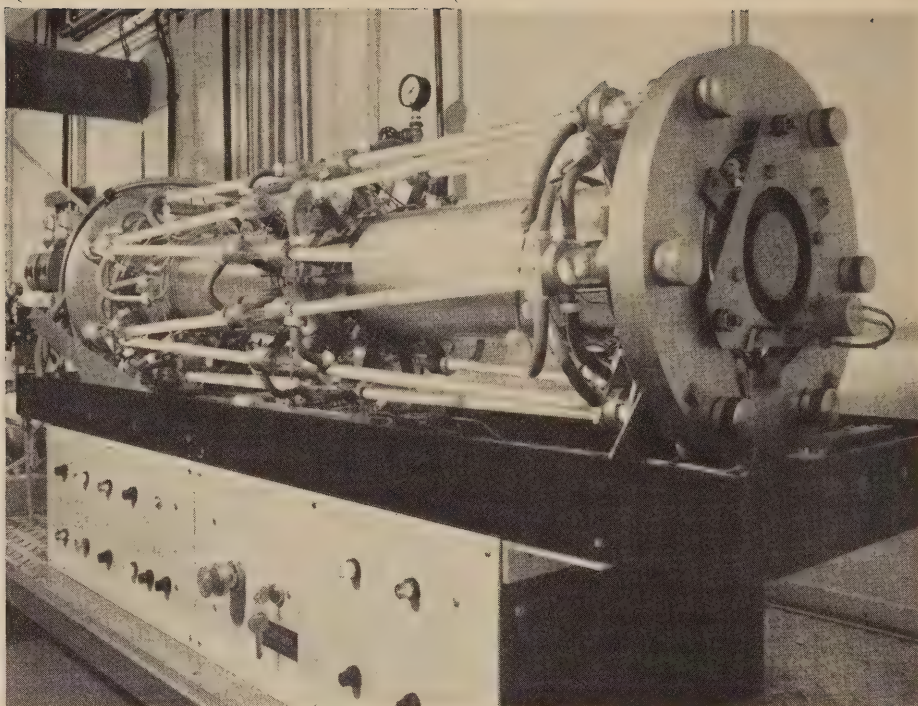
an agreed basis. Since nearly 10,000 proposals for the operation of broadcasting stations have been received, the conference will have the difficult task of accommodating demands within the 15 l.f. channels and 120 m.f. channels available. The process of negotiation will be extremely complex, since economic use of frequencies depends upon interdependent calculations across national borders, and computers are necessary to work out even small adjustments.

The United Kingdom's present usage of frequencies in the l.f./m.f. range has been submitted as the basis for its bids at the negotiating table, but it remains to be seen how much the present level of interference will be reduced in view of the large demand for frequencies both in Europe and the developing world. The prospects for a successful outcome for the conference must therefore remain a very open question.

The outcome of the conference will be extremely important to the Annan Committee which is considering the future structure of broadcasting in the UK. The Committee is due to report at the end of 1976.

Design Council Awards 1975

Carbon Dioxide
Multi-Fold Laser MF400



Among the ten Design Council Awards for engineering products and components this year, there are four engineering products and six engineering components chosen from a total of over 150 submissions.

The engineering products which have been selected include the Ferranti multi-fold laser and the Vickers scanning inter-

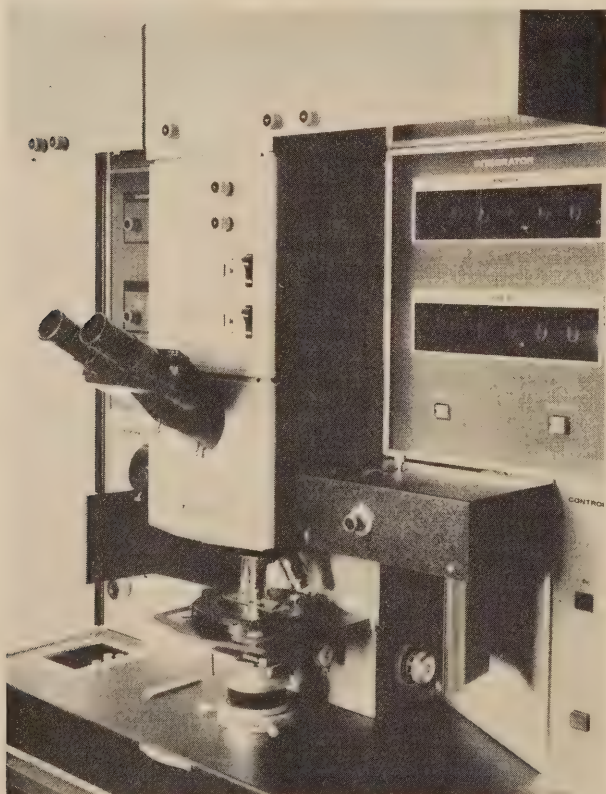
ferometer and microdensitometer as outstanding examples of the high technology and innovation which British industry produces. These are both equipments of considerable interest to electronic engineers.

A carbon dioxide gas laser which produces a continuous wave beam source for laser cutting systems, the Ferranti MF 400, is unique in that its discharge tube is folded into 12 sections. The multi-fold technique reduces the size of the MF 400 to 1.5 m long by 0.5 m square and makes it the smallest laser in the world for its rated power output. A conventional laser of the same power as the Ferranti MF 400, nominally 450 watts, would be about 9 m long. The advent of the MF 400 laser has created new markets and applications, solving a number of different, and laborious cutting and drilling problems in thin sheet metals, wood, quartz and plastics.

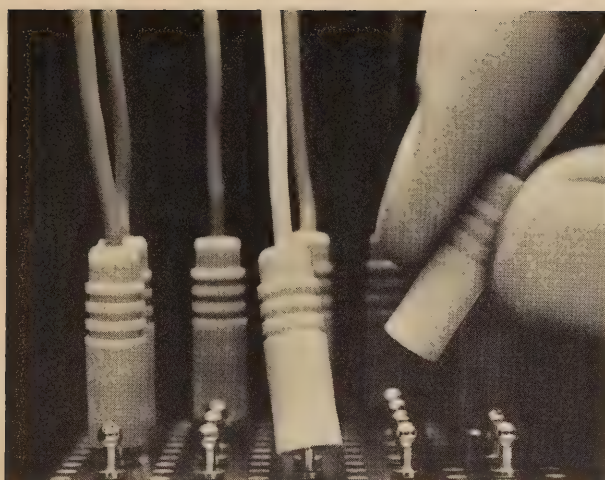
Designed and manufactured by engineers with a long standing association with precision instruments, the Vickers Ltd. M85/M86 scanning interferometer and microdensitometer is an optical instrument which is widely used in genetic studies including plant hybridization, as well as in biological studies such as the measurement of hormone content. The M85/M86 has been designed to maintain its accuracy without regard to length of time it has been switched on and the instrument has been engineered to give trouble-free running with the least possible maintenance. All the usual problems associated with interferometry measurements, including judging darkness of the object being viewed, are eliminated by the electronic measuring system which is a vital part of the instrument. As a result accuracy of measurement is improved and operator fatigue is minimized.

All six manufacturers who have won a 1975 Design Council Award for engineering components have concentrated considerable attention on making their equipment reliable. Ten of these components are particularly relevant to the electronics industry.

Invented by Robert F. Oxley, chairman of Oxley Developments Co. Ltd., the Snaplox is an electrical connector based on the ball and socket principle. The ball is on the upper

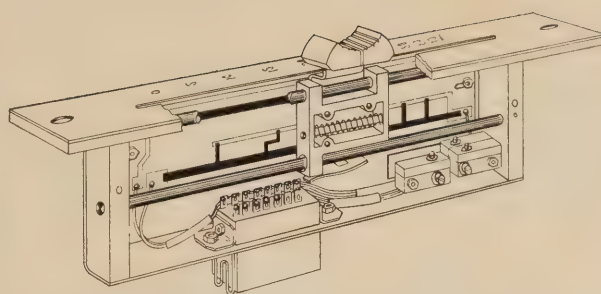


Scanning Interferometer and Microdensitometer



Oxley Snaplox Electrical Connector

end of a spill which is designed for fixing in a printed circuit board and the socket is sheathed to the end of a wire lead. The socket is designed for easy manipulation on and off the ball. An audible 'click' provides positive indication of correct socket mating on the ball. When the flying socket is pulled sideways gently beyond a generous angle, it detaches itself. Under normal conditions the socket will pivot freely within a 60° solid angle and prevent any transmitted stress causing damage to the printed circuit board, ball end or adjacent components. This connector has a consistently low contact resistance.



Penny and Giles conductive plastics studio fader

Produced as a result of technological spin-off from the aerospace industry, the technical superiority of the Penny and Giles conductive plastics studio fader is stated to have made other designs obsolete. In construction the fader consists of a slider which is moved longitudinally by light finger-pressure upon a knob. The slider carries wiping contacts which pick off the voltage from a conductive plastics track. This voltage has a direct relationship with the knob position as indicated on a calibrated scale.

The fader provides a smooth, stepless voltage variation, has a flat frequency response and a life longer than the recording console in which it fits. In addition its high reliability is particularly appreciated in live broadcasting situations. Ergonomically its smooth linear motion is preferred by operators and its unique operating 'feel' enables far more sensitive use of the instrument.

Conference on 'Video and Data Recording'

In 1973 the IERE organized a very successful conference, held at the University of Birmingham, on 'Video and Data Recording'. Since that date the fields of video recording and data recording have continued to draw closer together and the time now seems appropriate for a further conference to be held on this subject. Thus the second Video and Data Recording Conference will be held from 20th to 22nd July 1976, and the venue will again be the University of Birmingham. The Institution of Electrical Engineers, the Institute of Physics, the Royal Television Society, the Institute of Electrical and Electronics Engineers and the Society of Motion Picture and Television Engineers are associated with the Conference.

The organizing committee, which is under the Chairmanship of Mr. R. Larry and includes representatives from Industry, Broadcasting Organizations and Universities, now invites papers for the Conference. The following list of headings provides a guide to the topics on which papers are sought:

Theory of Recording Processes

Magnetic Recording Media, Techniques and Hardware

Video—broadcast, industrial, domestic

Computer—disk, tape and other storage devices

Instrumentation

Advances in recording media—metallic films, chromium dioxide, high energy particles, etc.

Transport systems—tape, disk, cassette

Recording and replay heads

Duplication—recent advances

Coding and Modulation

P.c.m., f.m., phase, amplitude and adaptive modulation; time compression and expansion; error detection, correction and concealment.

New Application Areas

New Recording Techniques and Media

Mechanical—plastic disk; electron beam; holographic; laser beam including magnetic-optic memories; magnetic bubble devices. Thin film and magnetic resistant heads.

In the first instance a synopsis should be submitted. This should be long enough (typically about 200 words) to enable the committee to assess the scope of the proposed paper, and should be sent to the Joint Conference Secretariat, Institution of Electronic and Radio Engineers, 8-9 Bedford Square, London WC1B 3RG. Synopses should be submitted without delay.

Final papers may be either in short form or full length, i.e. containing either 2,000 words or 4,000 words approximately. They will be pre-printed and are, therefore, required in final form by 20th February 1976.

Further information and registration forms for the conference will be available in due course from the Conference Secretariat.

The Purpose of an Exhibition

Air Vice-Marshal Davidson opens the Leeds Electronics Exhibition

The annual exhibition of electronic equipment staged by the University of Leeds is opened in alternate years by the Presidents of the IERE and of the IEE or their representatives. For this year's event Air Vice-Marshal S. M. Davidson, C.B.E., (Vice-President) deputized for the IERE President.

Air Vice-Marshal Davidson said that in his professional role as a senior RAF electronics engineer he was interested in all such exhibitions, representing, as ACDS(S), a major customer of the electronics engineering training machine and industry. He continued: 'This event is clearly much more than just a commercial show, held in this splendid academic setting and including a most important programme of lectures and discussions on a wide range of topics of high professional interest to electronic engineers involved in the teaching, research, development and production fields.

'But there are no doubt some who would say that there is little real point in putting on a commercial exhibition of this sort in these hard times—even accepting the wider and more diverse benefits which I have mentioned. And many of those critics would plead, too, that this is not the time to be buying new electronic equipment. But, as the representative of a major customer of the electronics industry, I would not support their view.

'I would support ventures of this sort at this time simply because I believe that modern electronics is potentially able to provide the keys which can readily open some of the gates on the path to greater efficiency—and, above all, higher productivity—in so many areas of the nation's work: which is surely the one and only route which leads to a lasting solution to our nation's economic problems.

'This "more-out-for-less-in" philosophy dominates much of our thinking in defence communications and electronics planning at present. And in the present harsh financial climate I don't see that our experience in the Ministry of Defence can be very different to that of top managers in other high-technology based enterprises.

'This is where electronics seem to me to have so great and so unique a part to play today: to help men do the job faster and so save time (which is as good as, and sometimes more valuable than, money): to take the boring chores out of work and so to increase both the productivity of, and quality of life for, the worker: to minimize equipment down-times by simplifying and speeding up servicing processes; to identify and call attention to system performance degradation and so permit early remedial action and forestall catastrophic failure; to reduce in communications systems the number of lines or circuits needed to pass any given volume of traffic; to get more and better service out of the already overcrowded electromagnetic spectrum; and above all, to get the men and women out of manpower-intensive systems and so reduce the overall cost of the process for, as we in the RAF know only too well, high quality manpower is so desperately

expensive that it must be cut if the scale and quality of the output function of any such system is to be maintained when input funds are limited. Such manpower is, in any case, urgently needed for more profitable work elsewhere.

'Properly channelled and exploited, current electronics technology, available design expertise and established production techniques can be harnessed to great effect in all these areas of activity today. Will I find such ideas, devices and developments here at Leeds—and above all, if I do find them, will they be straightforward adequate low-cost solutions to my problems: or unnecessarily elegant attempts at perfection at a price I cannot afford to pay?

'This particularly troublesome time in our nation's history is as good a time as any other for staging an exhibition of this sort: electronics can—indeed must—help in its own unique way in today's special situation just as it has helped in other ways in earlier more dangerous or more affluent times. And if all those concerned in electronics—students, teachers, research workers, development and production engineers, and marketing men (many of whom are drawn together by this unique annual event) are pointing their endeavours towards that end and can show us the results at exhibitions such as this, only good for the nation, and for them, can result.'

Standard Frequency Transmissions—August 1975

(Communication from the National Physical Laboratory)

August 1975	Deviation from nominal frequency in parts in 10^{10} (24-hour mean centred on 0300 UT)	Relative phase readings in microseconds NPL—Station (Readings at 1500 UT)	
	Droitwich 200 kHz	*GBR 16 kHz	†MSF 60 kHz
1	0	687.8	609.4
2	−0.1	688.0	609.4
3	−0.1	688.0	609.4
4	−0.1	688.0	609.4
5	−0.2	688.0	609.4
6	−0.2	688.2	609.3
7	−0.2	688.4	609.3
8	−0.2	688.4	609.3
9	−0.2	688.6	609.5
10	−0.2	689.0	609.5
11	−0.1	689.6	609.5
12	0	689.4	609.6
13	+0.1	689.6	609.8
14	0	690.0	609.8
15	0	690.1	610.0
16	+0.1	690.3	610.3
17	+0.1	690.3	610.6
18	+0.1	690.6	610.6
19	+0.2	690.8	610.6
20	0	690.8	610.4
21	+0.1	690.5	610.6
22	+0.1	690.4	610.5
23	+0.1	690.6	610.5
24	+0.2	690.8	610.7
25	+0.2	691.0	610.7
26	+0.2	690.7	610.7
27	+0.2	690.7	610.8
28	+0.1	690.8	610.8
29	+0.1	690.9	610.7
30	0	691.0	610.8
31	+0.1	691.0	610.9

All measurements in terms of H-P Caesium Standard No. 334, agrees with the NPL Caesium Standard to 1 part in 10^{11} .

* Relative to UTC Scale; (UTC_{NPL}—Station)
= + 500 at 1500 UT 31 December 1968.

† Relative to AT Scale; (AT_{NPL}—Station)
= + 468.6 at 1500 UT 31 December 1968.

INSTITUTION OF ELECTRONIC AND RADIO ENGINEERS

Applicants for Election and Transfer

THE MEMBERSHIP COMMITTEE at its meeting on 4th September 1975 recommended to the Council the election and transfer of the following candidates. In accordance with Bye-law 23, the Council has directed that the names of the following candidates shall be published under the grade of membership to which election or transfer is proposed by the Council. Any communication from Corporate Members concerning the proposed elections must be addressed by letter to the Secretary within twenty-eight days after the publication of these details.

Meeting: 4th September 1975 (Membership Approval List No. 212)

GREAT BRITAIN AND IRELAND CORPORATE MEMBERS

Transfer from Member to Fellow

CHEESBROUGH, John William. *Walsall, Stafford.*
PATON, Robert Kenneth. *London.*
TATNALL, Dennis Sydney. *Shenfield, Essex.*

Direct Election to Fellow

HARRIS, Douglas James. *Gosport, Hampshire.*

Transfer from Graduate to Member

O'DRISCOLL, Florence A. *Waterford, Republic of Ireland.*
SMITH, Ian M. *Warrington, Cheshire.*

NON-CORPORATE MEMBERS

Transfer from Student to Graduate

THOMPSON, Stuart A. *Canterbury, Kent.*

Direct Election to Graduate

PATEL, Suryakant. *Gillingham, Kent.*
ROBINSON, Geoffrey N. *North Shields, Tyne and Wear.*
ZANKER, Philip M. *Worthing, Sussex.*

Transfer from Graduate to Associate Member

CHOLERTON, Peter M. *Colchester, Essex.*

Direct Election to Associate Member

EDDU, Martin R. *London.*
HILL, Brian D. *King's Langley, Hertford.*
PERKIN, John H. *Ashington, Northumberland.*

Transfer from Student to Associate

REDFERN, Frank C. *Penarth, Glamorgan.*

OVERSEAS

CORPORATE MEMBERS

Transfer from Member to Fellow

HUME, Cyril Robert. *New Jersey, USA.*

Transfer from Graduate to Member

BHATT, Kukkemane C. *Bangalore, India.*

NON-CORPORATE MEMBERS

Transfer from Student to Graduate

AGBOGIDI, Godwin O. M. *Efferun-Warri, Nigeria.*
HO, Chung Hong. *Kowloon, Hong Kong.*

Direct Election to Graduate

ANDREOU, Michael. *Nicosia, Cyprus.*
MCGHIE, Patrick A. *Kingston, Jamaica.*

Transfer from Student to Associate Member

FOLORUNSHO, Augustine A. *Kaduna, Nigeria.*

Direct Election to Associate Member

AKPABIO, George A. *Eket, Nigeria.*
IOANNOU, Gregorius N. *Limassol, Cyprus.*
POBEE, George K. *Accra, Ghana.*

Direct Election to Associate

ABDIN, Mohamed R. *Hawalli, Kuwait.*
AVITZUR, Chaim. *Jerusalem, Israel.*

STUDENTS REGISTERED

CHAN, Wing Cheung W. *Hong Kong.*
FAKIYESI, Solomon O. *Ondo, Nigeria.*
FUNG, Cheuk Ho. *Kowloon, Hong Kong.*
HO, Kheng Guan. *Singapore.*
PANG, Kum Heng. *Singapore.*
TENNAKOON, Mudiyanselagie A. *Wattala, Sri Lanka.*
TEO, Ee Hoi. *Singapore.*

New Linear Accelerator for Harwell

The Harwell Atomic Energy Research Establishment is to have a powerful new electron linear accelerator (Linac) to update and improve its capabilities for research in support of the nuclear power programme. By firing the beam into a suitable target, the new machine will be used as a source of very short bursts of fast neutrons for underlying nuclear physics studies, fast reactor development, materials studies and later on for studies relating to thermonuclear fusion reactors. Treasury approval has been given for the expenditure of £2.8M spread over a period of four years.

The new machine will have a maximum beam energy of 136 MeV and will replace Harwell's present 55 MeV Linac, which came into operation in 1958. To maintain continuity of work, and at the same time to keep costs down, it will make use of much of the existing Linac equipment, including, in particular, the neutron booster which multiplies the neutron pulse by a factor of ten. The present machine will continue to be used until the new one becomes operational, probably in 1978.

The new Linac will provide beams of electrons and neutrons very much higher in intensity than anything at present available in the UK. It will consist of eight sections each having a 2-metre long wave-guide. It will be driven by four TV2001W klystrons rated at 20 MW peak r.f. power and 40 kW average r.f. power. The open-circuit maximum electron energy of the machine is specified to be 136 MeV and the energy for 0.75 A current in long pulses is 80 MeV. The first two sections of the accelerator will be arranged so that they can be operated independently of the main Linac to

provide low energy electron beams within the range 2 to 30 MeV.

The maximum pulse current for long pulses (up to 5 μ s) is 1 A (for which the electron energy is 60 MeV) and under these conditions the pulse repetition frequency is 300p/s, corresponding to a maximum delivered electron power of 90 kW. The maximum duty cycle for electron pulses is 3×10^{-3} . The maximum pulse current in short pulses (10 ns) is 6 A. The shortest pulse available is 5 ns and the maximum pulse repetition frequency is 2000 p/s.

Many of the facilities in the existing machine will be incorporated in the new one, in particular the neutron booster and the evacuated neutron time-of-flight tubes which range from 5 metres to 300 metres in length. The existing computer and data collection facilities will also be retained.

Beams of neutrons having carefully selected energies have long been used for investigating the behaviour and properties of atomic nuclei and the physics of solids. Sir John Cockcroft originally proposed the use of electron linear accelerators as sources of pulsed neutrons for this purpose, and by the early 1950s a 3 MeV machine was in use at Harwell, to be followed by a 17 MeV one. In 1959, the present 45 MeV machine was built there by Vickers Ltd. of Swindon. This machine has been equipped with a 'booster' or neutron-multiplying assembly which remains a unique facility for neutron physics. In this device the electron beam falls on a heavy metal target generating high energy gamma rays which, in turn, give rise to photo-neutrons. These neutrons enter a sub-critical mass of uranium which multiplies the neutron pulse by a factor of ten.

Forthcoming Institution Meetings

London Meetings

Thursday, 6th November

JOINT IERE-IEE COMPUTER GROUP

Colloquium on DISTRIBUTED INFORMATION SYSTEMS

IERE Lecture Room, 2 p.m.

'The British Steel Corporation's Data Communications Network'

By D. Bradley (*Ferranti*)

'Information Dissemination and Retrieval by Teletext Techniques'

By J. Lloyd (Software Sciences) and S. Rhys-Williams (*Jasmine Electronics*)

'VIEWDATA—A Public Information Retrieval Service'

By M. Smith (*Post Office*)

'Distributed Scrap Book: An Information Utility'

By D. M. Yates (*National Physical Laboratory*)

Advance registration necessary. For further details and registration forms, apply to Meetings Secretary, IERE.

Wednesday, 12th November

AUTOMATION AND CONTROL SYSTEMS GROUP

Colloquium on WEDDING CALCULATORS TO INSTRUMENTS

IERE Lecture Room, 10 a.m.

Papers will include:

'Development Philosophy of Programmable Calculator Hardware' and

'The HATRA Instrumental Colour Pass/Fail System using the Harrison/Shirley Digital Colorimeter'

By R. Tinson (*Wang Electronics*) and S. M. Jaekel (*HATRA*)

'The P.652 Microcomputer System' and 'Application of a Microcomputer to Control Production Equipment'

By D. Aggleton (*British Olivetti*) and D. Moon (*Metal Trim*)

'Marriage of Calculators to Systems'

By W. Davies (*Monroe International*) and N. J. Challacombe (*Keithley Instruments*)

'The Hewlett-Packard Interface Bus—A New Method of Interfacing Instrumentation'

By D. Peacock (*Hewlett-Packard*)

'The Use of Calculators in the Automation of Data Acquisition' and

'A Description of its Implementation'

By P. Wilde (*Tektronix UK*)

Advance registration necessary. For further details and registration forms, apply to Meetings Secretary, IERE.

Wednesday 26th November

COMPONENTS AND CIRCUITS GROUP

Colloquium on INDUSTRIAL CATHODE-RAY TUBES

POSTPONED

Thursday, 27th November

AEROSPACE, MARITIME AND MILITARY SYSTEMS GROUP

Papers on the Mediator Project

'Air Traffic Control Systems in the United Kingdom'

By G. E. Graham (*National Air Traffic Services*)

'The Development of Radar Data Processing Facilities used in the U.K. Air Traffic Control System'

By F. K. Spokes (*National Air Traffic Services*) and T. H. Clark (*Plessey Radar*)

IERE Lecture Room, 6 p.m. (Tea 5.30 p.m.)

Thursday, 4th December

AUTOMATION AND CONTROL SYSTEMS GROUP

Dynamic Systems Checkout

By Professor D. R. Towill (*UWIST*)

IERE Lecture Room, 6 p.m. (Tea 5.30 p.m.)

Wednesday, 10th December

COMPONENTS AND CIRCUITS GROUP

Colloquium on THE ELECTRONICS OF ELECTRONIC ORGANS

The Engineering Lecture Theatre G6, University College London, Torrington Place, London WC1, at 2 p.m.

Advance registration necessary. For further details and registration forms, apply to Meetings Secretary, IERE.

Southern Section

Thursday, 30th October

Electromagnetic Compatibility—A perspective

By L. J. Fountain (*School of Signals, Blandford*)

Farnborough College of Technology, 7 p.m.

Military radio equipments, both co-sited and distant, present differing compatibility problems. These are outlined, and the current approaches to their solution are discussed.

Wednesday, 12th November

Aspects of V.H.F. Reception

By R. S. Broom (*University of Southampton*)
Southampton College of Technology, East Park Terrace, Room 413, 7.30 p.m.

V.h.f. broadcasting developments in the past ten to fifteen years provide material for a timely progress review of solved and unsolved problems. This is the period of transition from monophonic to stereophonic broadcasting and the latter has, in many respects, accentuated the problems encountered during the establishment of the monophonic national v.h.f. network. There are three areas of research/engineering for review: (a) Band II spectrum utilization and broadcast coverage nationally and in

terms of European broadcasting; (b) significant propagation effects; and (c) receiver development/performance from the monophonic to the stereophonic functions.

Friday, 14th November

Hybrid Integrated Microwave Amplifiers

By Dr. S. J. Hewitt and R. S. Pengelly (*Plessey*)

Isle of Wight College of Arts and Technology, Newport, 7 p.m.

The types of transistor and the various forms of circuit element suitable for use in integrated microwave amplifiers are reviewed. The procedure for computer-aided design of these amplifiers is outlined and illustrated with f.e.t. amplifiers operating within the range 4–12 GHz.

Wednesday, 19th November

JOINT MEETING WITH IEE

Applications of Semiconductor Devices to Protection

By M. C. S. Simpson (*GEC*)

Lanchester Building, University of Southampton, 6.30 p.m.

Wednesday, 26th November

Future Developments in Primary Radar Systems

By Dr. K. Milne, O.B.E. (*Plessey Radar*)
Portsmouth Polytechnic, Park Road, Room ABO 11, 7.30 p.m.

After a brief review of the history of the development of primary radars, the principal problems facing designers—ground clutter, sea clutter, weather clutter, angel echoes and interference—are outlined. Approaches to the solutions of these problems are surveyed and examples given of current practice.

Future trends in primary radars are discussed in the light of recent advances in automation and in signal processing techniques. Improvements in the immediate future are likely to be evolutionary in nature, aimed at making the performance of today's radars compatible with more automated control systems. The case for more radical longer-term changes is examined; these may range from the introduction of relatively simple three-dimensional radars into air traffic control systems to adaptive multi-function radars using inertialess scanning techniques for defence systems. Possible approaches to future systems designs aimed at achieving moderate cost solutions to clutter and interference problems are discussed.

Tuesday, 2nd December

Opto-Electronics—Illuminating the Future

By R. J. Abraham (*Hewlett-Packard Ltd*)
School of Signals, Blandford Camp, Blandford, 6.30 p.m.

Wednesday, 3rd December

JOINT MEETING WITH IEE

Impact of Behaviour Science in Management

By P. Sadler (*Ashridge Management College*)
Southampton Technical College, 6.30 p.m.

Wednesday, 10th December

Aspects of V.H.F. Reception

By R. S. Broom (*University of Southampton*)
Lecture Theatre 'F', University of Surrey,
Guildford, 7 p.m.
For synopsis see 12th November meeting.

Kent Section

Thursday, 27th November

Recent Advances in Calculator Technology

By R. Bradbeer (*Guildford Tapes and Calculators*)
Medway and Maidstone College of Technology,
Maidstone Road, Chatham, 7 p.m.

Thames Valley Section

Tuesday, 4th November

Electronics in Medicine

By Dr. D. W. Hill (*Royal College of Surgeons*)
Caversham Bridge Hotel, Caversham Road,
Reading, 7.30 p.m.

Thursday, 4th December

Terotechnology

By H. Lukes (*Slough College of Further Education*)
School of Electronic Engineering, REME,
Arborfield, 7.30 p.m.

East Anglian Section

Thursday, 30th October

JOINT MEETING WITH IEE

Some Aspects of Modern Loudspeaker Design

By G. Bank (*Rank Radio International*)
The University Engineering Laboratories,
Trumpington Street, Cambridge, 6 p.m.
(Tea 5.30 p.m.).

Wednesday, 5th November

JOINT MEETING WITH IEE

Viewdata—an Interactive Information Service for the General Public

By S. Fedida (*Post Office*)
Great White Horse Hotel, Tavern Street,
Ipswich, 6.30 p.m. (Tea 6 p.m.)

Wednesday, 12th November

Communications of the Future

By Dr. P. D. Whitaker (*University of Birmingham*)
The Audio Visual Centre, University of
East Anglia, Norwich, 7 p.m.

Thursday, 27th November

JOINT MEETING WITH IEE

Videodisc

Speaker from Mullard

The University Engineering Laboratories,
Trumpington Street, Cambridge, 6 p.m.
(Tea 5.30 p.m.)

Wednesday, 10th December

Teletext—Information Display on the Home Television Receiver

By J. R. Kinghorn (*Mullard*)
The Civic Centre, Chelmsford, 6.30 p.m.
(Tea 6 p.m.)

South Western Section

Thursday, 13th November

JOINT MEETING WITH IEE

ORACLE—A Broadcast Information Service

By D. Wood (*IBA*)
Plymouth Polytechnic, 7 p.m. (Tea 6.30
p.m.).

Wednesday, 19th November

CEI MEETING

Engineering for Survival

By Professor Meredith Thring (*Queen Mary College*)
Lecture Room, School of Chemistry,
University of Bristol, 7 p.m. (Tea 6.30 p.m.)

Monday, 1st December

JOINT MEETING WITH IEE

Open University Engineering Courses—An Outsider's View

By Dr. S. L. Hurst (*Bath University*)
Queen's Lecture Room, University of
Bristol, 6 p.m. (Tea 5.30 p.m.)

South Wales Section

Thursday, 30th October

JOINT MEETING WITH IEE

Computer Graphics

By A. J. Davies (*University College, Swansea*)
Lecture Room B, Physics Department,
University College, Swansea, 6.30 p.m.
(Tea 5.30 p.m.).

It is pertinent to ask the question whether we are making proper use of the power available from the high-speed digital computer and whether the user-machine interface could be improved. The requirements of a basic graphics system will be described with the aid of video recordings, and certain advanced graphics facilities will also be illustrated. It will be shown how computer generated graphics has proved a powerful tool for research and teaching in many fields of science and engineering and particular reference will be made to the use of graphics in the study of (a) bacterial motion; (b) ionization and electrical breakdown in gases; and (c) fluid mechanics.

Wednesday, 12th November

ANNUAL GENERAL MEETING OF THE SECTION

Followed at 6.30 p.m. by

The Omega System of Navigation

By Dr. R. C. V. Macario (*University College, Swansea*)
Dept. of Applied Physics and Electronics,
UWIST, Cardiff, 6.15 p.m. (Tea 5.30 p.m.).

Wednesday, 10th December

JOINT MEETING WITH INSTITUTE OF PHYSICS

Solar Energy and its Applications

By B. J. Brinkworth (*University College Cardiff*)
Room 164, Department of Chemistry,
UWIST, Cardiff, 6.30 p.m. (Buffet after
lecture)

Beds & Herts Section

Tuesday, 18th November

Large Scale Integrated Circuits for Teletext Decoding

By D. Spicer (*Texas Instruments*)
Room 7/1, Mander College, Bedford,
7.45 p.m. (Tea 7.15 p.m.).

'Teletext' is a system of transmitting alphanumeric and graphics display information over existing television channels by the addition of digital data to unused television lines in the field blanking interval. The BBC and the IBA are both transmitting Teletext services called CEEFAX and ORACLE respectively. In order to receive Teletext transmissions the television receiver must be fitted with a decoder incorporating linear circuits and around 1200 logic gates. This paper discusses the design of large-scale integrated circuits to enable sufficiently low decoder cost for incorporation in domestic television receivers.

South Midland Section

Tuesday, 11th November

JOINT MEETING WITH IEE

Microprocessors

By Dr. E. L. Dagless (*University College of Swansea*)
Queen's Hotel, Cheltenham, 7.30 p.m.

Wednesday, 10th December

Electronics in Seismic Exploration

By M. J. Hughes (*Seismographic Service (England)*)
Foley Arms Hotel, Malvern, 7.30 p.m.

West Midland Section

Thursday, 20th November

JOINT MEETING WITH CEI

Space Technology

By G. K. C. Pardoe (*General Technology Systems*)
Vaughan Jeffreys Lecture Theatre, School
of Education, University of Birmingham,
6.30 p.m.

Monday, 8th December

JOINT MEETING WITH IEE AND IPOEE

'My Dear Watson . . .'

By G. Phillips (*Director, Police Scientific Development Branch*)

P.O. Training Centre, Stone, Staffs, 7 p.m. (Tea 6.30 p.m.)

East Midland Section

Tuesday, 11th November

JOINT MEETING WITH IEE

Dolby Noise Reduction System

By I. Hardcastle (*Dolby Laboratories*)

Lecture Theatre 'C', Chemistry Department, Leicester University, 7 p.m. (Tea 6.30 p.m.)

Wednesday, 10th December

JOINT MEETING WITH INSTITUTE OF PHYSICS

Sector Scanning Sonar

By Dr. A. R. Pratt (*Loughborough University*)

Lecture Theatre W.O.01, Loughborough University of Technology, 7 p.m. (Tea 6.30 p.m.)

Merseyside Section

Wednesday, 12th November

Radio Astronomy

By Dr. A. G. Lyne (*Jodrell Bank*)

Department of Electrical Engineering and Electronics, University of Liverpool, 7 p.m. (Tea 6.30 p.m.)

Wednesday, 10th December

Progress in Medical Instrumentation

By Dr. D. W. Hill (*Royal College of Surgeons*)

Department of Electrical Engineering and Electronics, University of Liverpool, 7 p.m. (Tea 6.30 p.m.)

Yorkshire Section

Tuesday, 11th November

Fly-by-Wire Flight Control Systems

By Flt. Lt. P. L. Hills (*RAF College, Cranwell*)

Botham's Cafe, Whitby, 7 p.m. (Tea 6.30 p.m.)

Wednesday, 19th November

JOINT MEETING WITH INSTITUTE OF PHYSICS

Electronic Control and Communications on Motorways

By Supt. W. A. Hambrey (*Midland Links Motorway Police Group*)

Department of Physics, Sheffield University, 7 p.m. (Tea 6.30 p.m.)

Wednesday, 26th November

JOINT MEETING WITH IEE

Signals and Systems—What do we know?

By D. Brook

Sheffield Telephone House, Charter Square, 6.30 p.m. (Tea 6 p.m.)

Thursday, 11th December

JOINT MEETING WITH IEE

The Faraday Lecture—The Entertaining Electron

By H. Steele (*IBA*)

Sheffield City Hall, 7.30 p.m. (Tea 7 p.m.)

Thursday, 18th December

One-day Colloquium and Exhibition on MICROPROCESSING

Leeds Polytechnic, 9.30 a.m.

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Further information is being sent to all members of the Yorkshire Section.

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North Eastern Section

Tuesday, 11th November

Underwater Navigation

By J. Bond (*Marconi Space and Defence Systems*)

YMCA Lecture Theatre, Ellison Place, Newcastle-upon-Tyne, 6 p.m. (Refreshments in Refectory from 5.30 p.m.)

Tuesday, 9th December

Practical Uses of Pattern Recognition

By Dr. J. R. Parks (*Department of Industry*)

YMCA Lecture Theatre, Ellison Place, Newcastle-upon-Tyne, 6 p.m.

(Refreshments in Refectory from 5.30 p.m.)

The lecture commences with a description of the fundamentals of character recognition and then considers some recent work concerned with signature validation. Automatic inspection of documents is also considered and current developments are reviewed.

North Western Section

Thursday, 13th November

Radio Astronomy—Bird's Eye View

By Miss Hilary Exton (*Cavendish Laboratory, Cambridge*)

Lecture Theatre R/H10, Renold Building, University of Manchester Institute of Science and Technology (UMIST), 6.15 p.m. (Tea 5.45 p.m.)

The last few decades have seen a vast expansion in the subject of astronomy. Prior to the 1940s, astronomy was limited to purely visual techniques; the sky was viewed at only optical wavelengths. Recent developments have made possible observations of the sky at X-ray, infra-red and radio wavelengths. Foremost of these is radio astronomy; sophisticated techniques have yielded huge quantities of information, clarifying existing theories of astronomy and cosmology and sowing the seeds of new ideas.

Thursday, 11th December

JOINT MEETING WITH IEE

Communications for the North Sea Oil Installations

By J. L. Bolton (*PO Telecommunications HQ*)

Lecture Theatre R/H10, Renold Building, University of Manchester Institute of Science and Technology (UMIST), 6.15 p.m. (Tea 5.45 p.m.)

Scottish Section

Thursday, 20th November

Integrated and Hybrid Circuits for the Amateur Constructor

By B. Dance

Napier College of Technology, Colinton Road, Edinburgh, 7 p.m.

Friday, 21st November

Integrated and Hybrid Circuits for the Amateur Constructor

By B. Dance

Boyd Orr Building, Glasgow University, 7 p.m.

Northern Ireland Section

Tuesday, 4th November

Voice Recognition by Computer

By Dr. R. Lingard (*Queen's University, Belfast*)

Cregagh Technical College, Montgomery Road, Belfast, 7 p.m.

Tuesday, 2nd December

Discussion Forum—The Role of the Engineer in Society

Panel of four speakers

Cregagh Technical College, Montgomery Road, Belfast, 7 p.m.



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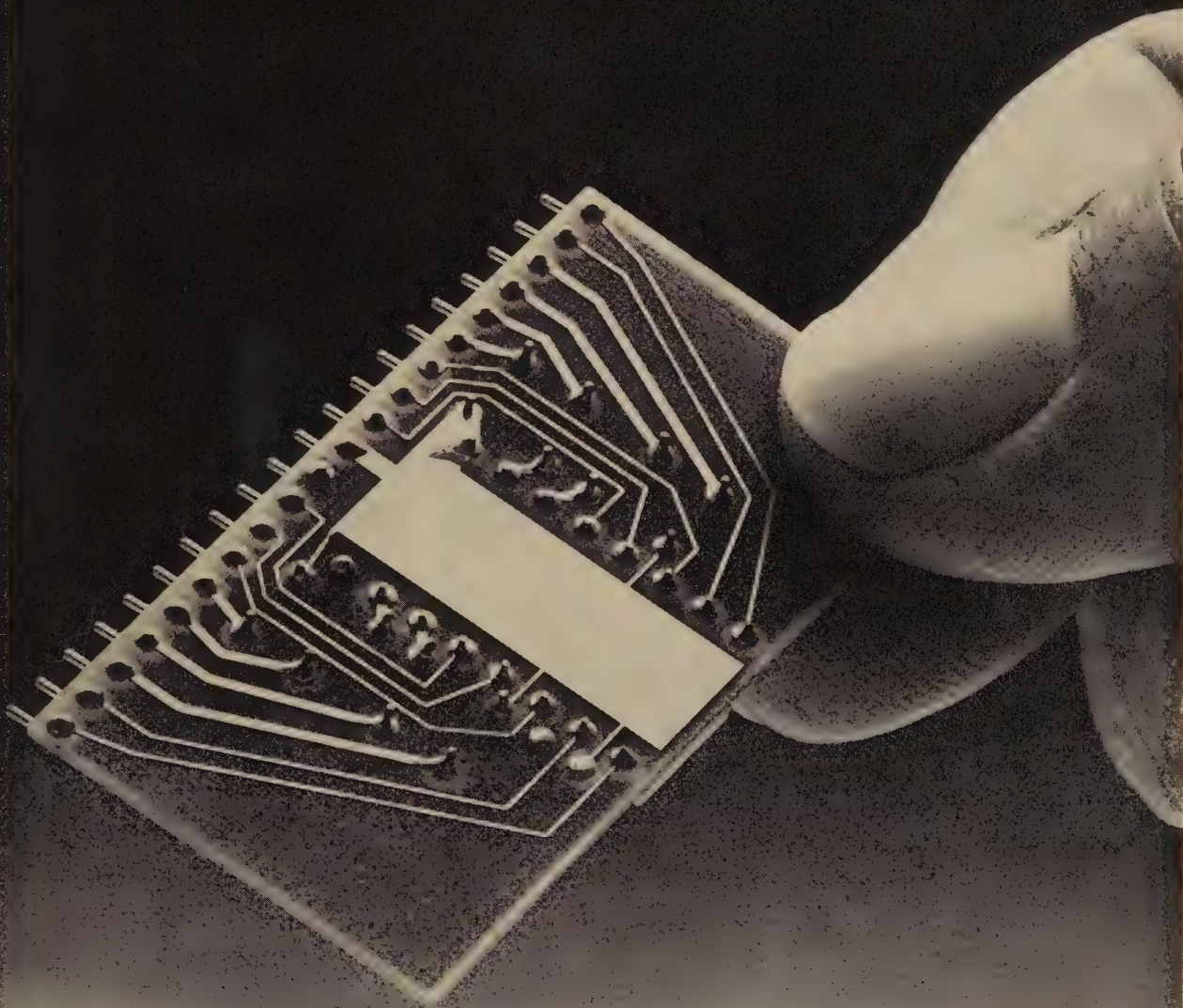
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Sessions will include the following typical papers:

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Mathematical Model, A.M./F.M. Receivers

PROPAGATION AND NOISE

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Reduction of Impulsive Noise, Origins of Radiated
Noise, Safety, Digital Transmission

USER SYSTEMS

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Further information and registration forms for the Conference are available from the
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Number	Title of Conference	Price	
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5	'Microwave Applications of Semiconductors' (London, 1965)	7·00	19·25
7	'Applications of Thin Films in Electronic Engineering' (London, 1966) — — — — — — — — — —	7·00	19·25
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19	'Electronic Engineering in Ocean Technology' (Swansea, 1970)	7·50	20·65
20	'Laboratory Automation' (London, 1970) — — — — —	7·00	19·25
21	'Electronic Control of Mechanical Handling' (Nottingham, 1971) — — — — — — — — — —	7·50	20·65
23	'Digital Processing of Signals in Communications' (Loughborough, 1972) — — — — — — — — — —	7·50	20·65
28	'Remote Control System Organization' (London, 1973) — —	2·50	6·90
29	'Environmental Sensors and Applications' (London, 1974) —	9·00	24·75
30	'Advances in Automatic Testing Technology' (Birmingham, 1975) — — — — — — — — — —	12·00	33·00
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Conferences, Courses and Exhibitions, 1975-76

1975

- November 4 LONDON
Conference on Piezoelectric and Pyroelectric Materials and Applications (IEE, IERE, IoP, IAE, IEEE)
Conference Department, IEE, Savoy Place, London WC2R 0BL

November 4-6 DUBLIN
First Electronics Exhibition for Ireland (ITRUN)
Euro Marketing Services Ltd., 9 Herbert Place, Dublin 2
(Tel. 681780)

November 5 STOKE POGES, BUCKS
One-day meeting on Physics of Detection and Surveillance
Meetings Officer, Institute of Physics, 47 Belgrave Square, London SW1X 8QX. (01-235 6111)

- * November 6 LONDON *September 1975, p. 506*
Fourth Cockcroft Lecture—Sir John Hill (BNES)
Institution of Civil Engineers, 1-7 Great George Street, London SW1P 3AA (Tel. 01-839 3611)

November 10-14 MANCHESTER
Automated Production Exhibition
Exhibitions for Industry Ltd., 157 Station Rd. East, Oxted RH8 0QF, Surrey

- * November 18-19 EASTBOURNE
Conference on The EEC and Instrumentation
Sira Institute Ltd., South Hill, Chislehurst, Kent BR7 5EH (Tel. 01-467 2636)

- November 18-20 TEDDINGTON, *September 1975, p. 509*
MIDDLESEX
Conference on Civil Land Mobile Radio (IERE, IEE, IEEE)
IERE, 8-9 Bedford Square, London WC1B 3RG

November 18-20 LONDON
Conference on Electrical Methods of Machining, Forming and Coating
Conference Department, IEE, Savoy Place, London WC2R 0BL
(Tel. 01-240 1871)

November 20-30 SAO PAULO, BRAZIL
1st International Mechanical Engineering and Electro-Electronics Trade Fair
British Joint Venture: W. Pickett, BEAMA, 8 Leicester Street, London WC2H 7BN (Tel. 01-437 0678)

November 25-29 BRUSSELS
21st Interélectronique
Union Professionnelle des Fabricants et Importateurs de Matériel Electronique, 74 Avenue Molière, 1180 Bruxelles (Tel. 345 7129)

November 28-December 7 GENEVA
4th International Exhibition of Inventions
Exhibition Secretariat, 22 rue du Mont-Blanc, CH-1201 Geneva, Switzerland

- * November 30-December 3 WASHINGTON
International Electron Devices Meeting
Mr. W. C. Holton, Texas Instruments Inc., P.O.B. 5936, Dallas, Texas 75222

- December 1-4 LONDON
Conference on Signal Filtering—Conference Cancelled

December 9-11 LONDON *October 1974, p. 572*
2nd International Conference on Electrical Safety in Hazardous Environments
Conference Department, IEE, Savoy Place, London WC2R 0BL

1976

January 5-7 MANCHESTER
13th Annual Solid State Physics Conference
Meetings Officer, Institute of Physics, 47 Belgrave Square, London SW1X 8QX (Tel. 01-235 6111)

The date and page references in italics at the head of an item are to issues of *The Radio and Electronic Engineer* in which fuller notices have been published. An asterisk (*) indicates a new item or information which has been amended since the previous issue. The symbol (●) indicates that the IERE has organized the event or is a participating body.

Further information should be obtained from the addresses given

- * January 6-March 16 LONDON
Course on Television Engineering Transmission and Reception I (1 meeting a week)
Polytechnic of North London, Department of Electronic and Communications Engineering, Holloway Road, London N7

- * February 18-20 PHILADELPHIA
International Solid State Circuits Conference
SSC Council, Philadelphia Section, University of Pennsylvania

- February 18-21 LONDON
Conference on Software Engineering for Telecommunication Switching Systems
IEE, Savoy Place, London WC2R 0BL (Tel. 01-240 1871)

March 2-19 TOULOUSE
Course on Space Technology—'Observation of the Earth'
Centre National d'Etudes Spatiales, Département des Affaires Universitaires, 18 Avenue Edouard-Berlin, 31055 Toulouse Cedex

- * March 9-11 ZURICH
International Seminar on Digital Communications
Mr. G. S. Moschytz, Eidgenössische Tech. Hochschule, Zurich 8006, Sternwartstr. 7, Switzerland

March 29-30 BRIGHTON
Conference on Materials and Processing Effects in Semiconductor Devices
The Meetings Officer, Institute of Physics, 47 Belgrave Square, London SW1 8QX (Tel. 01-235 6111)

- March 30-April 3 LONDON
Conference on Small Electrical Machines (IEE, IERE, IEEE, IoP)
IEE, Savoy Place, London WC2R 0BL (Tel. 01-240 1871)

- * April 5-10 PARIS
Salon International des Composants Electroniques
FNIE, 16 Rue de Presles, 75740 Paris, Cedex 15

- April 6-8 SOUTHAMPTON
Conference on Applications of Electronics in Medicine (IERE, IEE, BES)
IERE, 8-9 Bedford Square, London WC1B 3RG

- * April 7-9 HULL
Conference on the Teaching of Electronic Engineering in Degree Courses
Dr F. W. Stephenson, University of Hull, Department of Electronic Engineering, Hull HU6 7RX (Tel. (0482) 46311, ext. 7113)

April 11-14 THE HAGUE
Symposium on Marine Traffic Systems
Secreteriat SMTS, c/o Netherlands Maritime Institute, P.O. Box 25138 Rotterdam, The Netherlands

April 13-15 LONDON
The All-Electronics Show
Evan Steadman, 34-36 High Street, Saffron Walden, Essex CB10 1EP

- * April 13-15 LEEDS
Seventh L. H. Gray Conference on Medical Images
Dr. M. J. Day, Regional Medical Physics Department, Newcastle General Hospital, Newcastle upon Tyne NE4 6BE (Tel. (0632) 38811, ext. 512)

April 27-30 LONDON
2nd International Marine Exhibition (IMEX 76) and International Marine Shipping Conference (IMAS 76)
(British Marine Equipment Council, IMarE)
Brintex Exhibitions Ltd., 178-202 Great Portland Street, London WIN 6NH

- * April 27-June 1 LONDON
Course on Television Engineering Transmission and Reception II (1 meeting a week)
Polytechnic of North London, Department of Electronic and Communications Engineering, Holloway Road, London N7

● May 3-7 LONDON

2nd International Symposium on Subscriber Loops and Services
(IEE, IEEE, IMA, IERE, IMechE)
IEE Conference Department, Savoy Place, London WC2R 0BL
(Tel. 01-240 1871)

May 3-7 BIRMINGHAM

International Instruments, Electronics and Automation Exhibition and Electrex Exhibition (EEA, BEAMA & Others)
Industrial & Trade Fairs, Redcliffe House, Blenheim Court, Solihull, West Midlands B91 2BG

May 10-14 LONDON

January/February 1975, p. 88
VIIth Congress of the International Measurement Confederation (IMEKO)
Mr. S. S. Carlisle, Institute of Measurement and Control, 20 Peel Street, London W.8

May 11-24 BOSTON

Electro/76
IEEE, 3600 Wilshire Boulevard, Los Angeles, California 90010

May 17-21 ROTTACH-EGERN, FRG

7th IFAC Symposium on Automatic Control in Space
VDI/VDE-GMR, P.O. Box 1139, D-4000 Düsseldorf 1, FRG

May 22-26 BRUSSELS

3rd International Exhibition on Instrumentation and Automation Techniques—'Euromation'
3rd International IFAC Conference on Instrumentation and Automation in the Paper, Rubber and Plastics Industries—'P.R.P. Automation'
BIRA, Jan Van Rijswijcklaan 58, B-2000 Antwerp, Belgium
(Tel. (03) 38 65 24)

May 23-27 BIRMINGHAM

International Home Electronics and Domestic Appliances Exhibition (AMDEA, BREMA)
Andy Montgomery Ltd., 11 Manchester Square, London W1M 5AB (Tel. 01-486 1951)

May 28-31 BIRMINGHAM

Sound and Vision '76 Exhibition
Montbuild Ltd., 11 Manchester Square, London W1M 5AB
(Tel. 01-486 1951)

June 8-11 BRIGHTON

Communications 76—Third International Exposition of Communications Equipment and Systems
Tony Davies Communications Ltd., 1 Victoria Terrace, Ealing Green, London W5 5QS (Tel. 01-579 5941)

* June 14-16 PHILADELPHIA

International Conference on Communications
W. W. Middleton, Bell Tel. Co. of Pennsylvania, 1 Parkway, Philadelphia, Penns. 19102

* June 14-16 NEW JERSEY

International Microwave Symposium
Bernard DeMarinis, 492 River Road, Nutley, New Jersey 07110

June 15-19 DUSSELDORF

3rd International Conference and Exhibition—Interocean '76
NOWEA, Zentralbereich Inland 1, D-4000 Düsseldorf 30, Postfach 320 203, FRG (Tel. (0211) 4560-1)

● June 21-25 CAMBRIDGE

Conference on On-Line Operation and Optimisation of Transmission and Distribution Systems
Conference Department, IEE, Savoy Place, London WC2R 0BL

● June 28-July 2 CAMBRIDGE

Golden Jubilee Convention
IERE, 8-9 Bedford Square, London WC1B 3RG

● July 5-8 LONDON

International Conference on Automobile Electronics
IEE, Savoy Place, London WC2R 0BL (Tel. 01-240 1871)

● July 20-22 BIRMINGHAM

October 1975, p. 639
Conference on Video and Data Recording (IERE, IEE, RTS, IEEE SMPTE, IoP)
IERE, 8-9 Bedford Square, London WC1B 3RG

August 3-6 TORONTO

Third International Conference on Computer Communication (ICCC)
Dr. Pramode K. Verma, Program Chairman, ICC-76, P.O. Box 365, Station 'A', Ottawa, Ontario, Canada K1N 8V3

August 30-September 3 EINDHOVEN

Summer School on Electromagnetics and Antennas
Ir. E. J. Maanders, Electrical Engineering Department, Eindhoven University of Technology, PO Box 513, Eindhoven, The Netherlands

● September 1-3 LONDON

May 1975, p. 256
2nd Conference on Advances in Magnetic Materials and their Applications
(IEE, IERE, IoP, IEEE)
Conference Department, IEE, Savoy Place, London WC2R 0BL

September 6-11 NAMUR

VIIIth International Congress of Cybernetics (ASBL)
Association Internationale Cybernetics, Palais des Expositions, Place André Rijckmans, B-5000, Namur, Belgium.

● September 7-9 SWANSEA

Conference on Gas Discharges (IEE, IERE, IoP, IEEE (UKRI), Welding Institute)
Conference Department, IEE, Savoy Place, London WC2R 0BL
(Tel. 01-240 1871)

* September 12-16 WASHINGTON, D.C.

Engineering in the Ocean Environment—OCEAN 1976
IEEE, 345 East 47th Street, New York, N.Y. 10017

* September 13-17 BUDAPEST

Constronic '76—Second Conference on Mechanical Aspects of Electronic Design
HTE-Constronic '76, Scientific Society for Telecommunication, 1372 Budapest, P.O.B. 451, Hungary

* September 14-17 ROME

Sixth European Microwave Conference and Exhibition
Mr. Roger Marriott, Microwave Exhibitions and Publishers Ltd., 34-36 High Street, Sevenoaks, Kent TN13 1JG

September 19-22 EDINBURGH

Symposium on Gallium Arsenide and Related Compounds
Meetings Officer, Institute of Physics, 47 Belgrave Square, London SW1X 8QX. (Tel. 01-235 6111)

● September 20-24 LONDON

International Broadcasting Convention—IBC 76
(IEE, IERE, EEA, RTS, etc)
IBC, c/o Savoy Place, London WC2R 0BL

November 9-12 LONDON

International Conference on Millimetric Waveguide Systems
IEE, Savoy Place, London WC2R 0BL (Tel. 01-240 1871)

* November 15-19 BIRMINGHAM

Design in Action Exhibition and Conference (IED)
D. B. Graham, Fairs and Exhibitions Ltd., 21 Park Square East, Regents Park, London NW1 4LH (Tel. 01-935 8200)

● November 22-25 LONDON

International Conference on 'The Future of Aircraft All-Weather Operations' (IEE, IERE, IEEE (UKRI), IMA, RAES, RIN)
Conference Department, IEE, Savoy Place, London WC2R 0BL.
(Tel. 01-240 1871)

* December 5-8 WASHINGTON

International Electronic Devices Meeting
IEEE, 345 East 47th Street, New York, N.Y. 10017

December 1976 TEL-AVIV

4th World Congress of Engineers and Architects in Israel
ITCC Secretariat, 200 Dizengoff Street, Tel-Aviv, P.O. Box 3082, Israel (Tel. (03) 220122)

1977

* May 23-27 LONDON

International Conference on Electricity Distribution—CIRED 77
(IEE, AIM)
IEE, Savoy Place, London WC2R 0BL (Tel. 01-240 1871)

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